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Potential of Passive DVB-T Radar Component Against Illegal UAV Flights

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Abstract

For now many years, illegal UAV (Unmanned Aerial Vehicle) flights have been observed in different countries and under various environments. The intent of such illegal flights may cover industrial espionage up to terrorist attacks. Countering such an asymmetric threat is now of increasing and challenging interest for many countries. The main compulsory functions for such an anti-UAV system will be briefly discussed from detection, localization, identification/classification, extraction (an UAV has to be isolated from other detections) to the alert function. After this introduction about the context, a description of a passive DVB-T (Digital Video Broadcasting Terrestrial) radar component will be given, and its potential, in regard to the previously described functions, will be illustrated using experimental results. Such a passive approach will be shortly compared with active radar components. Several measurement campaigns have been conducted with quite a huge variety of nano-small UAVs (multirotors such as ANAFI, Mavik, Phantom 4, F450 up to M600 as well as fixed wings such as ranger, Disco, X8 and X11) evolving under various configurations (bistatic bases, different weather conditions) and a selection of the most meaningful results will be presented.

Keywords: countering illegal UAV, passive radar, DVB-T (Digital Video Broadcasting-Terrestrial), clutter cancellation, detection, localization, identification/extraction, experimental results

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1. Introduction

Due to their proliferation during the recent years, UAVs have become a critical and, furthermore, an asymmetrical threat. Some years after the first UAV intrusions or attacks, some solutions began to exist. However, due to the multiplicity of the threats and their constant evolution, it is generally difficult to evaluate the real efficiency of the different concepts. Furthermore, the different compulsory functions for an anti-UAV system, are, quite often, assigned to dedicated sensors or sensor types and such an approach may face, in practice, a lack of efficiency.

In a first preliminary part, a short description of the different compulsory functions will be given. These definitions are required as they may differ from one kind of sensor to another. Due to the diversity between the sensor specialties, these definitions could not be universal but will be used within this document. The main sensor types that may contribute to each function will be mentioned.

The rest of the paper will be dedicated to radar component and more especially to passive radar component and its potential interest.

In particular, the second introductory part will compare the active radar approach with the passive radar one.

Then the principle and constraints of a passive DVB-T radar component will be reminded and discussed in order to introduce its potential interest for countering UAVs.

The last chapter will illustrate passive DVB-T capabilities, using some of the most meaningful experimental results. The interest of such a sensor for the different functions required for countering UAVs will be discussed.

2. *Compulsory functions of a counter-UAV system*

The document will consider the different following compulsory functions for a counter-UAV system:

- Detection: the objective is to decide, among other potential 'targets', about the existence of an UAV within a large angular and range sector.
- Localization: the UAV (among the other detected targets) has to be localized according to the receiving system or more globally its Cartesian coordinates have to be evaluated with respect to the area of interest.
- Tracking: the UAV and its kinematic features have to be evaluated by a tracking approach using the different localization measurements.
- Extraction: the UAV has to be extracted from the other targets with no interest and this UAV has to be tagged as a potential threat.
- Identification: the UAV may be identified according to its size, its potential dangerousness, its category (fixed wing or multirotor).
- Alert: the UAV has to be classified as a real threat or not. It could be achieved, for example, by localizing an identified UAV within a forbidden area.
- Neutralization: the UAV has to be neutralized in order to avoid the attack or even the simple intrusive incursion.

Among the main types of sensor, we may mention the following:

- Goniometric components: these sensors estimate the direction of arrival of an electromagnetic source within their bandwidth of survey. They generally look for some video flux or typical links between the UAV and its pilot. Then an association of different non-collocated goniometric components will allow the localization of the UAV. Finally such sensors contribute to the detection, localization and extraction (that could even be achieved directly using the signal identification and so before the detection phase) for UAVs which are transmitting characteristic signals.

- Radar components: these sensors estimate parameters of the slow moving targets within their environment. These parameters are typically range, radial velocity and angle(s) of arrival (azimuth and elevation for two-dimensional array antennas). Then these parameters may be used for localization and tracking.
- Acoustic components: these acoustic sensors are able to detect the noise sources and estimate their azimuth and elevation directions.
- Optical components: such components are generally considered for target identification even if some emerging solutions began to be studied for detection.

Most of the existing -or under development- systems combine the advantages (and drawbacks) of the different technologies in order to reach the final objective before neutralization: detect, localize, track, extract, and identify the UAV from all the other potential 'targets' within the area of interest.

However, it is noticeable that multiplying the number of sensors is not the optimal solution in terms of cost nor efficiency. For example, a simple radar-based system for detection, localization and tracking combined with an optical component for UAV identification and extraction, may not be fully efficient in terms of reactivity. Assuming a radar with high sensitivity but unable to limit the number of tracks of no interest, this radar would systematically ask for a confirmation/identification to the optical means, and such a systematical request is not efficient according to a reactivity criteria. This simple example outlines the interest of sensors mainly dedicated to detection and localization but with some classification capabilities.

3. Radar objectives and potential solutions

3.1. Radar objectives

The main missions for a radar sensor in such a counter-UAV context are the following:

- Detection and surveillance
  Radar should ensure a continuous surveillance of a wide angular sector with a high data renewal rate of the target parameters. The targets that should be detected are more specifically small targets at low altitude and low speed. The radar should also be efficient when facing multiple simultaneous attacks.

- Localization and Tracking
  Radar should restitute the Cartesian coordinates of the targets with respect to the area of interest.
- Identification/extraction
  As mentioned at the end of previous paragraph, a first step of identification at the radar level will lead to a substantial gain for a global system of alert. Consequently, an efficient radar should, ideally, have some identification capabilities or at least should avoid a systematic request to the identification component for all the detected targets.

From a footprint and deployment point of view, the radar component should be compatible with a fast installation on most of the area of interest. These criteria are scenario-sensitive as, for example, for specific long-planned events, an installation within one day could be considered as fast enough. However, a system requiring huge host infrastructure due to its wide footprint and consequent weight would be more complicated to deploy.

3.2. Battle field radar

Among the potential radar solutions, Battle field Radars [1, 2] are dedicated to terrestrial targets detection and tracking for targets ranging from pedestrians to tanks. Consequently, these radar sensors have been evaluated against UAVs. Such systems are generally X-band radar with a carrier frequency close to 10 GHz, the angular the monitored sector is close to 120° and the data renewal rate, for each target/direction, is typically close to 1.5 s. All of these active systems scan the 120° sector by focusing the energy with a typical angular step close to 1.5°. This focalization could be achieved mechanically (rotating antenna), electronically or numerically (by applying dedicated differential phases between the antennas of the transmitting array). These parameters imply a duration of illumination per scanned direction close to the ratio between the data renewal rate (here 1.5 s) and the number of directions (here let us say eighty), so close to 20 ms per direction or per expected target. However, as it will be explained later, for radar systems, it is, sometimes, possible under some hypothesis to detect the period of modulation induced by the blade rotation. As a typical blade rotation speed is between 6000 and 9000 rotations per minute, corresponding to a frequency between 100 and 150 Hz. A coherent integration time of 20 ms leads to a frequency resolution of 50 Hz. Consequently, such a frequency resolution is generally not sufficient for detecting the blade modulation which is only twice or three times the resolution (furthermore the UAV body contribution has a higher level than the blade modulation impact). Consequently, the discrimination/identification capabilities of such a radar component against UAV may be limited in practice.

3.3. Holographic radar

Some recent solution in L-Band (typically close to 1.5 GHz) has been developed [3], which is based on a monostatic approach with a constant illumination over ninety degrees and the surveillance of such a wide sector is achieved using the beamforming principle at the receiver level. This principle is sometimes called holographic principle. The main advantage of such an approach is the following: as the angular sector to be supervised is constantly illuminated and the observation of the different directions within this wide sector is achieved by numerical beamforming, all the targets/directions of arrival are analyzed simultaneously, and the coherent integration time per target/direction could be increased in order to ensure sufficient frequency resolution to conduct blade modulation analysis. The main drawback for such a solution relies in its weight and footprint.

3.4. Passive radar and more especially DVB-T

Passive radar systems have now been studied for a long time and were recently adapted for countering UAVs [4–7]. Such passive radar were originally studied for detecting low altitude targets at low speed in complement of active radars.

Classical passive radars are based on the exploitation of civilian illuminators of opportunity such as FM (Frequency Modulation), DAB (Digital Audio Broadcasting), DVB-T (Digital Video Broadcasting-Terrestrial) and more recently Wi-Fi [8, 9] for more local applications.

These broadcasters of opportunity present the following compulsory advantages for radar purpose: constant illumination, quite omnidirectional coverage, illumination ensured at the ground level. The basic information such as frequency and the main signal parameters are known. The locations of these radio-television civilian broadcasters are known, and these services generally offer a good density of transmitters. It has been evaluated that for countering UAV, among FM, DAB and DVB-T transmitters, DVB-T transmitters seem to be the most promising ones. Furthermore as the table 1 illustrates, DVB-T has the highest carrier frequency and the highest useful bandwidth among these three candidates.

In this chapter, the principle of a passive radar will not be detailed, only the main differences between typical passive radar approaches and the passive DVB-T sensor that will be detailed in the rest of this paper will be considered.

As historically, passive radar using FM, DAB, DVB-T were studied for ensuring a global coverage at low altitude, a basic passive component is typically based on a 8-antenna system per frequency band (FM, DAB or DVB-T) in a circular configuration to ensure omnidirectional surveillance. Consequently, for each direction, the angular resolution relies on only 3 to 4 antenna leading to a poor angular resolution. Such an antenna configuration induces a target localization

Table 1. Main parameters for the most common passive illuminators of opportunity.

	FM	DAB	DVB-T
Density	**High**	**Medium and poor in some countries**	**Medium**
Frequency carrier band of interest	[88–108] MHz	[170–230] MHz	[460–860] MHz
Useful band	Close to 30 kHz	1.5 MHz	7.5 MHz
Radiated power for powerful pylones	>10 kW	>10 kW	>10 kW

based on the association of multiple receiving systems (and a single transmitter) separated from a few kilometers (according to the objective: low altitude targets and not necessarily UAVs) or one receiver using multiple transmitting pylons or any combination of three bistatic couples. Whether there are based on multiple receivers or multiple transmitters, these three bistatic couples are required for tracking initialization based on 'bistatic range triangulation' [10], then the track itself may be maintained with only two bistatic couples and up to one. However, as this initialization phase requires a simultaneous detection over three different bistatic couples, the domain of localization is lower than the union of the three bistatic domains of detection.

The system considered in the rest of this document, is based on a sectorial coverage due to sectorial receiving antennas. This system was studied for critical infrastructure that could not consider omnidirectional sensors due to the complexity of the buildings infrastructure of the site to be protected. Then the omnidirectional protection will be based on the association of several of these sectorial sensors. Among the advantages of such a sectorial approach, we may mention the ability of managing all the antenna resources for a given sector in order to obtain a good angular resolution for each sector (always considering 8 antennas as a reasonable and reference complexity for a radar component). Another interesting consequence is the possibility of achieving, as soon as the target is detected, accurate bistatic localization for all the targets simultaneously. This point will be illustrated in the paragraph presenting the results. Concerning footprint and complexity considerations, even for a simple infrastructure protection, an omnidirectional surveillance typically leads to the installation of between four and six sectorial components on a single location in comparison with two or three receiving systems (the DVB-T transmitter density in some countries such as France is not so high) separated from a few kilometers with a common simultaneous coverage for track initialization. According to the expected domain of localization, and to the criticality of having a sensor potentially outside of the critical infrastructure domain, the advantages and drawbacks of each approach have to be analyzed for each specific configuration.

The next paragraph will present more in detail the sectorial DVB-T sensor exploited in this paper.

4. Sectorial passive DVB-T sensor

4.1. Main steps of passive radar signal processing

DVB-T signals, as all the civilian communication broadcasted signals, are continuously transmitted in order to broadcast information. Accordingly, it is impossible to isolate the receiving system from the transmitting one using the classical monostatic solution: for monostatic radar transmitting pulses with a period of repetition, the receiver is listening only when the transmitter is silent. In conclusion the passive receiver continuously records the direct path as well as the clutter contributions. All these fixed contributors have high power signal to noise ratio and the related side lobes after matched filter will present a high level of side lobes level to noise ratio in all the (range, Doppler) measurement domain. Without efficient cancellation, before the matched filter implementation, of all these fixed paths contributions, such a side lobes level after matched filter will prevent most of the target detections.

The COFDM (Coded Orthogonal Frequency Division Multiplexing) signal used for DVB-T could be schematized as follows: a continuous succession of coded symbols. Each symbol is based on the simultaneous transmission of many coded sinusoids and the code elements are modified from one symbol to the others.

$$S(t_m) = \sum_{k=1}^{K} C_m^k e^{j2\pi \frac{k}{T_u} t_m} \quad \text{with } t_m \in [m(T_u + \Delta), (m+1)(T_u + \Delta)] \tag{1}$$

Where:

T_u is the useful duration for each symbol

Δ represents the guard interval duration

$T_s = T_u + \Delta$ is the global duration of each symbol

t_m designates the time within the symbol m

K refers to the total number of transmitted sinusoids

k is the index of a current transmitted frequency

m is the time index of a symbol

C_m^k is the element of code broadcasted by the frequency k at the symbol m.

It is important to notice that this COFDM signal is called COFDM with guard interval (named Δ). Each symbol duration is higher than the useful duration T_u, T_u is the useful duration on which the transmitted sinusoids are orthogonal according to the Fourier transform over the duration T_u. This guard interval goal is to absorb potential interferences between the different frequencies and the different symbols for propagation channels with a length (delay between the first path and the last contributors) lower than the guard interval duration.

For example, for a propagation channel with a length L lower than Δ, it is possible to consider after synchronization on the first path, symbols at the receiving level that may be described as follows

$$S(t'_m) = \sum_1^K H_m^k C_m^k e^{j2\pi \frac{k}{T_u} t_m} \quad \text{and} \quad t'_m \in [m(T_u + \Delta) + L, (m+1)(T_u + \Delta)] \tag{2}$$

H_m^k is characterizing the propagation channel at frequency k and for symbol m.

As the previous expression is valid for duration equal to the difference between the whole symbol duration (sum of the useful duration T_u and the guard interval duration Δ) and the propagation channel length L, when this propagation channel length is lower than the guard interval duration, it is possible to analyze these received symbols on durations reduced to the useful duration, even after propagation within a limited (in time) channel.

Thus under this simple hypothesis about the propagation channel length, it is possible to consider the reception of symbols for which the orthogonality between sub-carriers is maintained despite the clutter contributions. And for each frequency k, the information recovered is the product between the channel response H_m^k and the transmitted code C_m^k.

Furthermore, usually, the propagation channel response could be considered stationary over durations at the scale of the coherent integration time used for matched filter and detection purpose; so we may consider a low dependency of this coefficient H_m^k according to m.

However, due to the delays between the different fixed echoes, this propagation channel coefficient is highly fluctuating with the frequency k.

Finally, the signal processing after the reception of COFDM signals will be based [11, 12] on the main following steps:

- A reference signal estimation is conducted in order to have an ideal reference of the transmitted signal for Matched filter purpose. This estimation is firstly based on the adaptation of the parameters (in time and frequency domains) of the receiving component accordingly to the transmitter parameters.

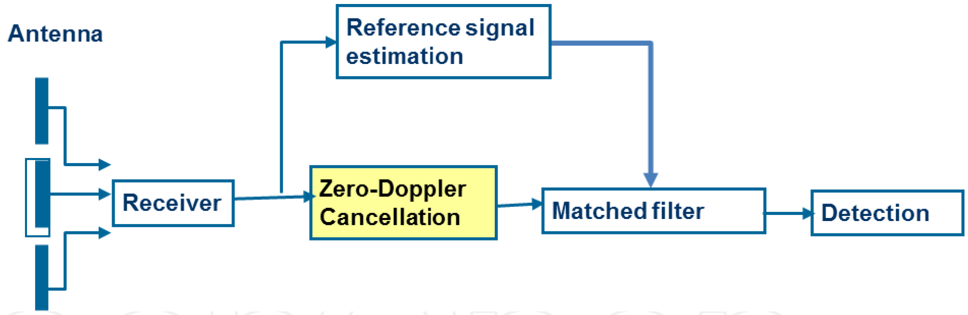

Figure 1. Schematic principle for a Passive DVB-T receiver.

These adaptations use specific properties of the COFDM signal. Then, within DVB-T symbols, some dedicated transmitted frequencies are called pilots and allow an estimation of the propagation channel response (combination between direct path and clutter elements), as for such pilots the transmitted code is known. One this propagation channel has been estimated, it is possible to reconstruct the entirety of the transmitted signal.

- The cancellation of all the fixed contributions before the implementation of the matched filter. This step is the most important one as it will avoid the side lobes related to the compression of such powerful unwanted zero-Doppler path. In practice, this cancellation is based on 'a projection orthogonal to the clutter response for each transmitted frequency'.
- Finally, a matched filter between the received signals after clutter cancellation and the reference signal issued from the demodulation principle (reference signal estimation) will allow the target detections.

These three main processing steps are illustrated on figure 1.

The figure 2 illustrates these signal processing principles and interest, the left part of the figure represents the (range, Doppler) ambiguity function without any zero-Doppler cancellation. The 'blue' level observed for the main part of the (range, Doppler) measurement domain corresponds to the superposition of the side lobes for all the fixed contributors.

The central figure represents different cuts: all the processing outputs have been normalized according to the receiver noise at 0 dB whatever we are considering the signal processing with or without zero-Doppler paths cancellation. The cut with a maximum close to 110 dB corresponds to the main direct path without clutter cancellation, the second cut with a level close to 37 dB corresponds to the direct path side lobes level at a bistatic range of 50 km. At such a 50 km bistatic range, the Signal to Noise Ratio is close to 5–7 dB after clutter (and direct path) cancellation. Finally, the last cut corresponds to the noise level.

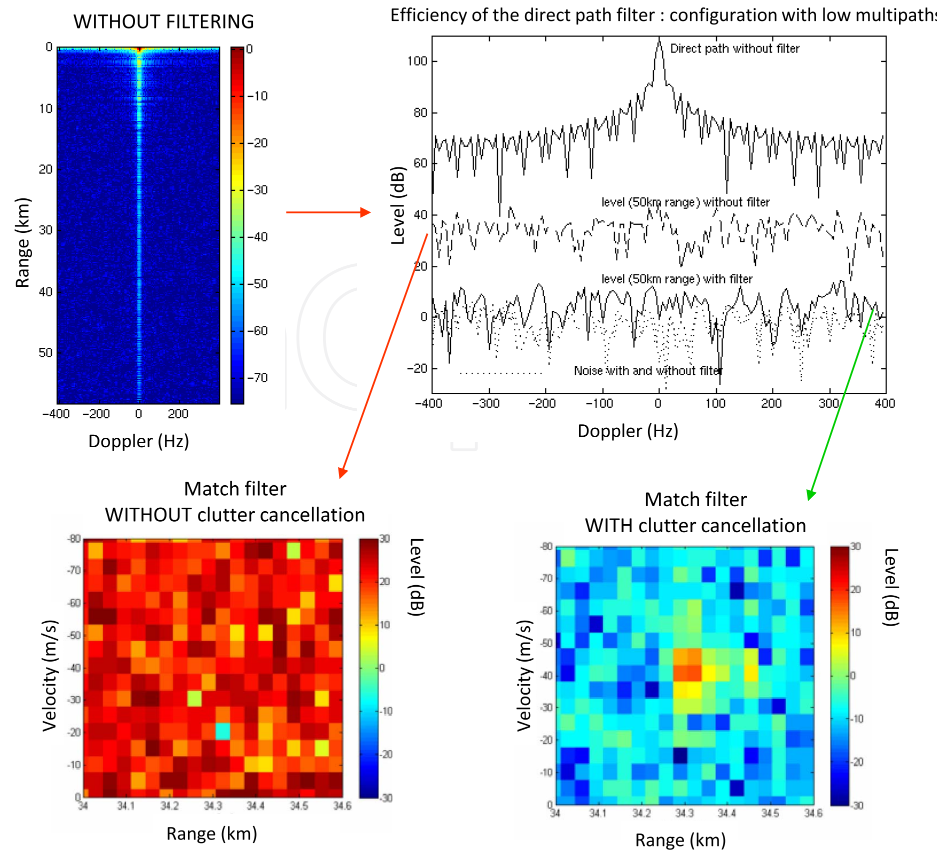

Figure 2. Illustration of the interest of zero-Doppler filtering for target detection.

The two small thumbnails at the lower part of figure 2 corresponds to a zoom around the (range, Doppler) domain close to a target (at the middle of the thumbnail). The left one is the matched filter output without zero-Doppler filtering and the uniform 'red' level corresponds to the direct path and clutter side lobes, the target is not detectable. The right one illustrates, that after direct path and clutter cancellation, the target is detected with quite a significant signal to noise ratio.

After the detection of the plots, the parameters of the target may be estimated: Bistatic range, Bistatic Doppler which corresponds to a direct measurement of the derivative of the bistatic range and the angle of arrival according to the receiving array.

4.2. Brief description of the sectorial DVB-T component: hardware and software

The receiving system is based on the following components:

Figure 3. Possible 2D-antenna array with 8 antennas.

- 8 yagui antennas installed on individual masts that could be organized in a two-dimensional array as illustrated figure 3 to estimate both the azimuth and the elevation angles.
- 8-channel hardware receiver allowing some gain adjustments and the selection of the frequency carrier corresponding to the transmitter of interest.
- A sampling component that digitalizes the signals after Hilbert filtering (so I and Q components). The system is able to process (see figure 1) the signals in real time while ensuring simultaneous records of the raw data for offline analysis.

Furthermore, as the angle of arrival (azimuth) is estimated with sufficient accuracy, a direct geometrical transformation of the (bistatic range, azimuth estimation) allows a bistatic localization according to the receiver location (range, azimuth estimation) or Cartesian (X,Y) coordinates.

4.3. Conclusions and advantages

Like the other passive systems, such a DVB-T passive sectorial component is able to cope with the main direct path and clutter limitations, which is a crucial step to detect targets at low altitude (so evolving in front of clutter contributors).

Due to the sectorial coverage with a dedicated 8-antenna array, it is possible to reach a good accuracy in azimuth domain and such a good azimuth precision combined with a good bistatic range resolution allows a direct bistatic localization by simple geometrical transformation between bistatic domain to Cartesian one.

5. Examples of experimental results

5.1. Short description of the bistatic configurations several ones

The different results presented hereafter were obtained under various bistatic conditions that are not mentioned for each individual result.

Generally in France, quite a limited number of powerful DVB-T transmitters may be used for a given receiver location: let say that over the different receiver locations evaluated the number of DVB-T transmitters of interest was between one and three.

According to their power and to the configuration, the range between the transmitter and the receiver varied from 30 km up to 110 km (transmitter installed on the top of a mountain.

5.2. Blade modulation detection: stationary quadrirotor and multirotor extraction

The typical coherent integration time for DVB-T component against UAV is between 0.5 s up to roughly 1 s. As mentioned previously, this is achievable as the transmitters are quite omnidirectional with a constant illumination and the sector to be protected is simply scanned numerically using our 8 antenna receiving array. All the targets within our sector of surveillance may be analyzed simultaneously (according to the digital beamforming efficiency). Such a long coherent integration time allows the detection of the blade modulation impact when the corresponding level is sufficient enough for ensuring its detection. This level depends on the blade material, the blade size,… but the conditions will not be discussed during this paper.

The blade modulation detections illustrated on figure 4 are corresponding to a stationary F450 (small quadrotor) at three kilometers away from the receiver. As the multirotor was in stationary configuration, it was impossible to detect the UAV itself while its blade modulation around 120–130 Hz were easily detected, the different modulation frequencies are corresponding to the different rotors.

The figure 5 clearly illustrates that numerous targets may be detected, but quite a few of them are presenting a behavior corresponding to target with blade modulation signature. The right part of figure 5 illustrates that the UAV had such a behavior and a small part of a 'trajectory' close to 6000 m bistatic range at the end of the record is also presenting such a behavior, this was probably due to a small aircraft with a frontal propeller.

The bistatic configuration was similar to the stationary flight illustrated on figure 4 but the small UAV was now achieving some small circles.

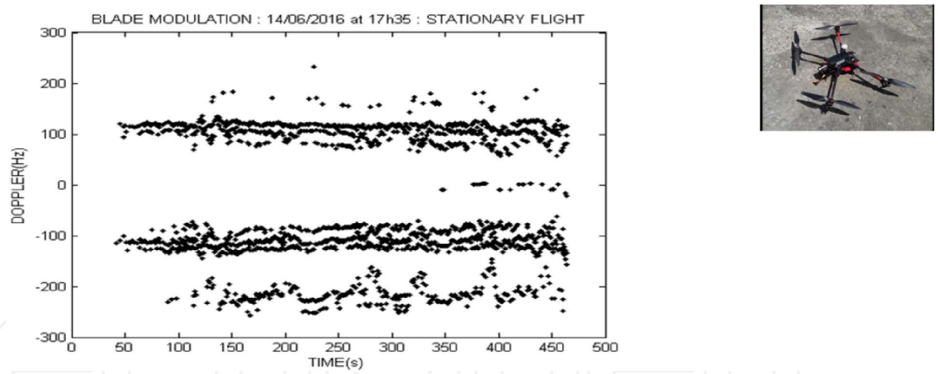

Figure 4. Blade modulation detection along time for a stationary flight.

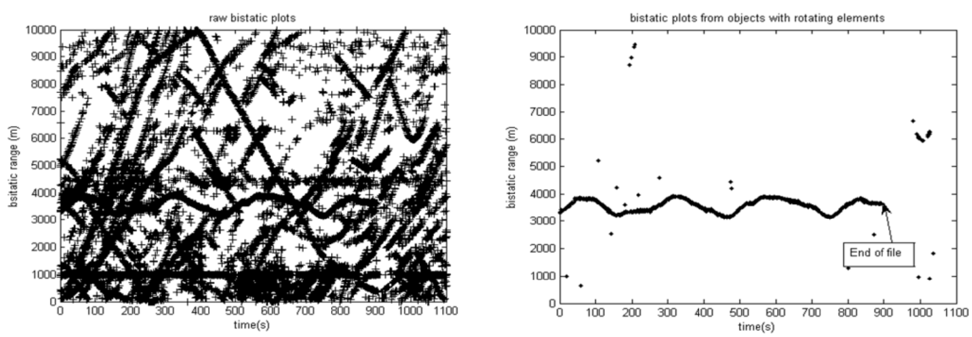

Figure 5. Exploitation of blade modulation detection for extracting the UAV from the other targets. Left part of the figure: all detected plots range history, right part: only the plots with a typical frequency signature corresponding to blade modulation were represented.

5.3. Fixed wing elongation: propeller detection, UAV extraction and bistatic localization

The results presented on figure 6 are corresponding to the direct bistatic localization algorithm (using the geometrical transformation from bistatic measurement to Cartesian coordinates with respect to the receiver (referred at (0,0) on the figure 6)). On the left part of the figure, green plots are corresponding to all the detected targets superimposed over 20 min records and the red ones are corresponding to the plots with a blade/propeller modulation behavior. The GPS ground truth is represented on the right part of the figure.

The frontal propeller impact was detected as soon as the fixed wing was facing the receiver even during the two loops. Furthermore, for closest configurations, the blade modulation effect was also detected when the UAV was no longer facing the receiver.

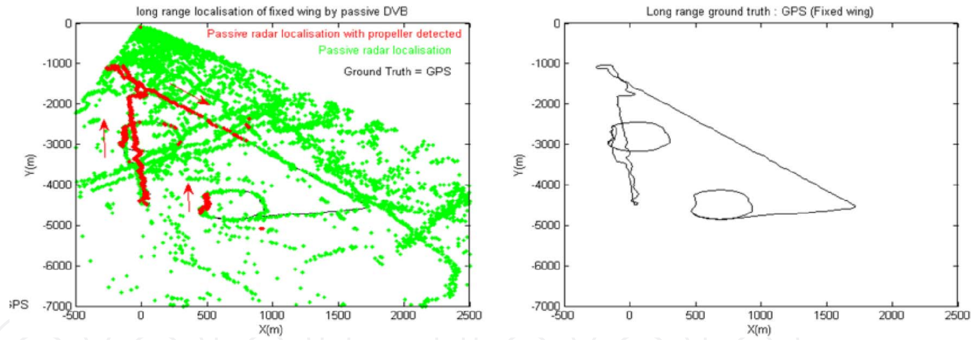

Figure 6. Fixed wing (with frontal propeller) detection over 20 min record. Left part: passive results with all plots over 20 min in green and plots with propeller/blade signature in red. The right part represents the ground truth trajectory.

The UAV localization fluctuations visible along Yaxis and close to 0 Xaxis coordinate are not errors, they are simply due to a transversal wind and they are also visible on the GPS ground truth.

5.4. Fixed wing localization: other bistatic configuration

The figure 7 represents, for another bistatic configuration, the comparison between the GPS ground truth (upper part of the figure) and the Passive DVB-T localization (lower part of the figure). The good behavior for both detection (with quite no losses of detection) and localization aspects are illustrated. The color is coding the time scale: blue dots represents older time stamps while red dots are for recent ones.

5.5. Multirotor detection and classification

The figure 8 illustrates two matched filter outputs for a M600 hexarotor at 1 km away from the receiver (left part of the figure) and then at 5 km away (right part of the figure). The three circles are corresponding to military aircrafts evolving during this trial. It has to be noticed that similar results for the M600 hexarotor were still obtained under foggy conditions.

5.6. Fixed wing: long range detection and localization

During one experimental campaign, it was possible to evaluate the detection capabilities of a fixed wing UAV (X8 and X11) up to ranges close to 10 kilometers away from the receiver. The results are illustrated on figure 9. The other detections/localizations are related to other targets (moving objects within our surveyed area) during this UAV flight. The UAV trajectory is outlined using the crosses indicating different specific waypoints of the trajectory: the beginning of the flight is marked with a dark blue cross, the half–turn is in blue and the end of the trajectory is marked with a red cross.

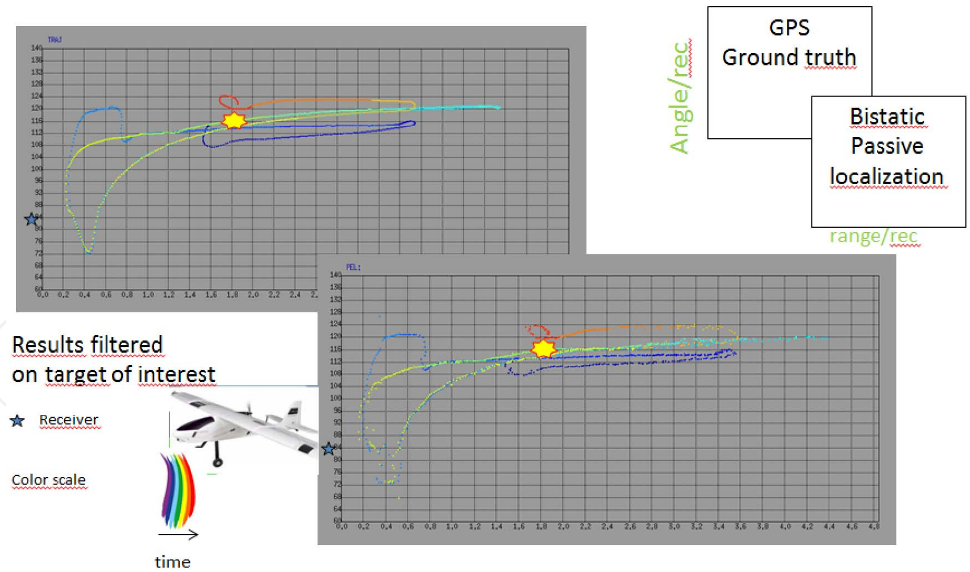

Figure 7. Fixed wing localization: comparison between GPS ground truth (upper figure) and passive localization (lower figure).

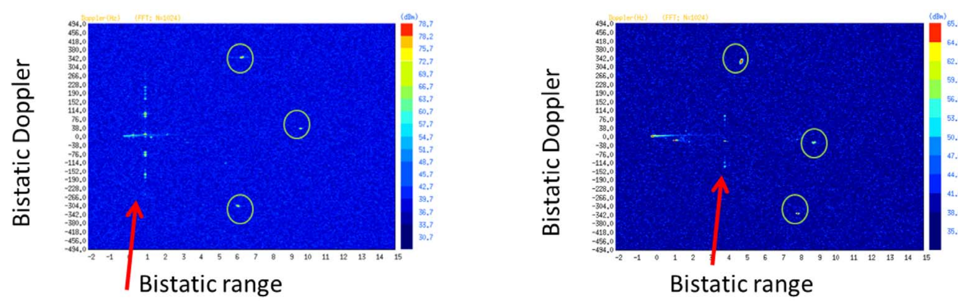

Figure 8. Illustration of typical 'instantaneous' frequency signature of the blade impact for a matrix M600 hexarotor. The left figure corresponds to a (target, receiver) range of 1 km while, for the right figure, the M600 UAV was 5 km away from the receiver. The two red arrows are only dedicated to outline the M600 frequency signature.

These results illustrate:

- The good and long range capabilities of such a passive DVB-T component. There is quite no losses of detection up to more than 9 km
- The accurate Cartesian localization capabilities using a single bistatic couple: one transmitter and one receiver.

However, it has to be mentioned that these results were obtained (using similar flights) twice over three attempts. The analysis of the missed ones (and of the successful ones) is still under progress.

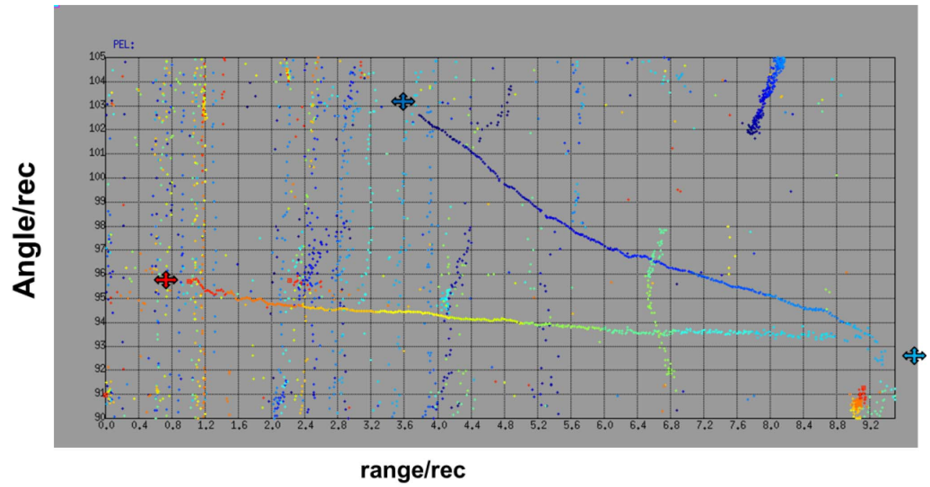

Figure 9. Long range detection and localization of a fixed wing UAV (X8 or X11).

Furthermore, these results also illustrate the need for a first ‘classification’ capability at the sensor level: the ‘isolated’ false alarms such as the ones at low ranges have to be avoided using, for example, a tracking function and ideally the coherent ‘tracks’ at the end have to classified as ‘none interesting targets’ as soon as possible. The next paragraph will suggest some possibilities for cancelling unwanted tracks occurring on roads.

5.7. Road detections rejection

As mentioned previously, passive DVB-T radars present interesting properties for UAV detection and localization. Nevertheless, it is of great importance to avoid systematic detections due to unwanted targets, such as terrestrial vehicles on roads. A simple way to limit a road impact is the following: each road will generally lead to numerous detections with (range, angle) histories that are characteristic of the geometrical configuration of this road according to the bistatic geometry. Once the accumulated (range, angle) domain corresponding to the numerous detections have been determined, it is possible to consider masks over these specific (range, angle) domains. Sometimes, it could also be possible to add the influence of the Doppler but this parameter may vary according to the car location along the road (traffic lights) or along the time domain (traffic jam) so managing this Doppler parameter is more complex for characterizing road detections. Figure 10 presents, on the left, the bistatic range histories of all the detected targets within 3000 and 9000 km, and on the right the remaining targets after the application of a (range, angle) mask corresponding to the accumulated plots along the road.

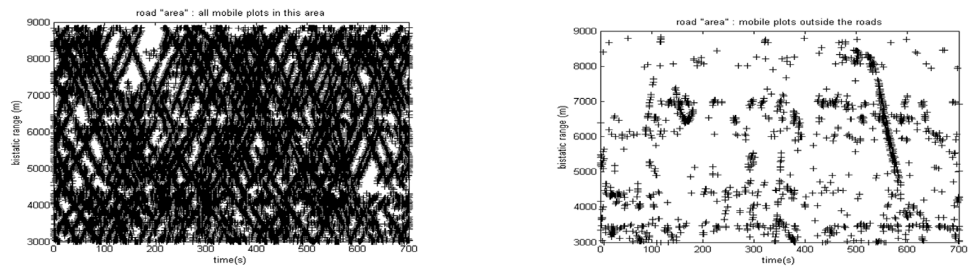

Figure 10. Example of cancellation of 'road' detections. The left figure illustrates the range history for a given bistatic range excursion, while the right one illustrates the situation after 'road' extraction.

6. Conclusion and future works

Countering illegal UAV flights is a complex challenge as the threat is in constant evolution. Furthermore, this struggle is highly asymmetric as UAV are low cost threats that could be easily deployed under various environments. Consequently it is crucial to evaluate anti-UAV system components with high efficiency and low sensitivity to the context.

The passive DVB-T radar component seems to offer interesting performances for both its detection capabilities and its Cartesian localization efficiency (even under simple bistatic configuration). Furthermore, it may offer some promising classification capabilities, for characterizing the UAV itself or for avoiding detections of unwanted targets. However up to now, this solution has mostly been evaluated for the protection of isolated infrastructures and its behavior in more complex environments needs to be confirmed.

The future works will mainly consist in the evaluation of such a DVB-T passive radar under more complex environments such as peri-urban ones. In parallel, the classification capabilities have to be enhanced in order to limit the number of systematic requests to an identification component such an optical one.

Conflict of interest

The authors declare no conflict of interest.

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