UAV Detection and Localization Using Passive DVB-T Radar MFN and SFN

Dominique Poullin
ONERA Palaiseau
Chemin de la Hunière BP 80100
FR-91123 PALAISEAU CEDEX
FRANCE

Dominique.poullin@onera.fr

ABSTRACT

For now many years [1] [2], passive radars using transmitters of opportunity have been studied and their capabilities and limitations for detecting and localizing "classical" air targets are now quite well known. The most famous transmitters of opportunity considered are FM, DAB (Digital Audio Broadcasting), DVB (Digital Video Broadcasting) [3] and more recently, some studies are dealing with WiFi transmitters[4].

However, despite the advantages of such passive radar components, such systems are not in use under operational forces. Our purpose is to illustrate a new promising interest of the DVB component by taking advantages of the DVB-T low altitude detection capabilities. As such DVB-T illuminators offer interesting range resolution at short ranges and very low to low altitude, DVB-T component has to be studied and evaluated for detecting and localizing UAVs in order to protect critical and/or isolated infrastructure.

At the end of 2014, many illegal drones flights were noticed among several European and none European countries showing a lack in the low altitude coverage for small slowly moving objects such as UAVs. Due to the passive DVB-T system capabilities such a survey objective could typically be addressed by such passive radar components.

This paper will illustrate and analyse several UAV detections at up to 3 kilometres in different bistatic and multistatic configurations.

1.0 INTRODUCTION

For a couple of years several illegal drone flights have been noticed in several countries leading to an analysis of the different surveillance systems able to cope with such malicious flights.

By considering a radar survey component, such a system has to ensure :

- Low and very low altitude coverage
- Detection of small and very small targets (typically up to a few kilogrammes by taking into account UAV such as DJI or similar)
- Detection of slow moving target with high manoeuvring capabilities
- Continuous detection from a few kilometres up to quite zero (so short range radar with no blind

zone).

- Detection 24h/24h.
- Preliminary discrimination capabilities between UAV and other mobile targets.

Such requirements may be fulfilled, sometimes after some adaptations, by :

- Battlefield radars
- Radars for monitoring the birds migration
- Passive DVB-T radars.

Our objective is to illustrate and demonstrate, by using several experimental results, the good behaviour of a passive DVB-T radar component for struggling against illegal UAV flights.

The first chapter will briefly present the main characteristics of the DVB receiver used during the different experiments and will analyse and verify the potential interest of such a passive DVB-T component by analysing most of the different requirements mentioned above.

The second chapter will illustrate the main different results obtained during the different experiments :

- modulation blades that are detectable by using such DVB passive radar.
- detection capabilities under several bi(multi)static configurations including a UAV detection in a SFN (Single Frequency Network) mode.
- location capabilities with such a system when using a single bistatic base.

In summary, this paper will focus on the validation of the passive DVB capabilities against illegal UAV flights by presenting experimental results corresponding to different (four among the five evaluated) bistatic configurations.

2.0 DVB RECEIVER CHARACTERISTICS AND COMPONENT INTEREST

2.1 DVB receiver characteristics

The DVB receiver used for all the results presented here is simply based on a

- Eight antenna system
- Each antenna is related to an analogue receiver channel
- All the eight antenna channels are digitalized
- And the processing is an off-line one

This system is able to record only one DVB frequency bandwidth per record.

The antennas are directional periodic antennas with a 3 dB aperture close to 50 degrees (+/- 25degrees).

The processing is classically based on the main following steps

- Reference signal reconstruction
- Direct path and clutter cancellation
- Correlation (match filter) over 0.5 second of coherent integration time.

2.2 DVB interest

The following table considers the different requirements related to the struggle against malicious UAV and evaluate the potential interest of a DVB solution

Requirements	DVB capability
Low and very low altitude coverage	DVB is known for its ground illumination and consequently for its interest at low altitude.
Small targets (DJI type)	Up to now most of the trials have been achieved with civilian small aircrafts at ranges of a few tenth of kilometres. So the detection of very small targets has to be investigated and some results will be shown in the following section.
Slow and manoeuvring targets	Due to the continuous DVB illumination, there is no physical drawback to integrate over long coherent integration time in order to increase the slow targets detectability.
Continuous detection from a few kilometres to zero	As mentioned previously small aircraft targets have been detected at ranges of a few tenth of kilometres so UAV at a few kilometres seem achievable (please see the following section results)
Detection 24h/24h	DVB-T is generally transmitting 24h/24h..
Discrimination capabilities : drone or not	This point is developed just after this table.

<u>Discrimination capabilities:</u>

Generally the UAV rotors have a rotation speed close to 8000-9000 rotations per second. For simplification purpose a rotation of 9000 rotations per second is considered: such a rotation leads to a periodicity of the received signal of 150 Hertz. Such a period is equivalent to the Doppler of a moving target with a bistatic velocity of 75 m/s (typical carrier frequency of 600 MHz) and as the classical signal processing for DVB-T is based on a (range,Doppler) analysis for targets from a few meters per second to a few hundred meters per second, the classical processing will allow the blade modulation detection if such a modulation level is sufficient.

In other words, without entering a specific discrimination mode, the blade modulation detection could be systematically observed for multi-rotors drone if the modulation level is sufficient. Some experimental results will be presented in the next section at ranges up to 3 kilometres.

3.0 DVB EXPERIMENTAL RESULTS

3.1 Modulation blades detection

The following example illustrates the blade modulation detection for a small multirotor achieving a stationary flight over a few minutes The multirotor was at roughly 3 kilometres from the receiver. The plots considered have been "filtered" by keeping only the plots whose range is close to the one of the stationary position.

At the beginning of the flight, the multirotor was at a too low altitude and some trees were hiding it.

Due to its velocity close to zero, during all the flight we were unable to detect the UAV itself (no detection around 0 Doppler), the "UAV detection" is achieved by the modulation blades detection which is closed to 100 and 150 Hz.

The different blade modulations are probably related to the different speed rotations of the rotors in order to maintain the stationary objective despite the wind effect.

Furthermore, it is also possible to detect partially (here negative Doppler) the second harmonics set of modulation blades.

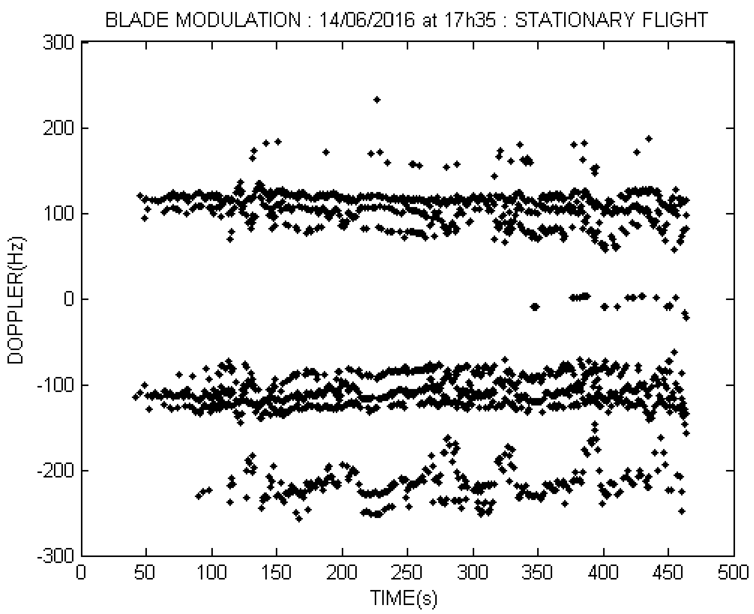

Figure 3-1: blade modulation (stationary multirotor at roughly 3 kilometres) with transmitter 1

This blade detection was observed with all the three potential illuminators represented on the schematic map below. The transmitter used for the results represented above is the first one Transmitter 1 located at 110 kilometres from the receiver. The second transmitter is 33 kilometres away from the receiver and the last one is distant from 85 kilometres.

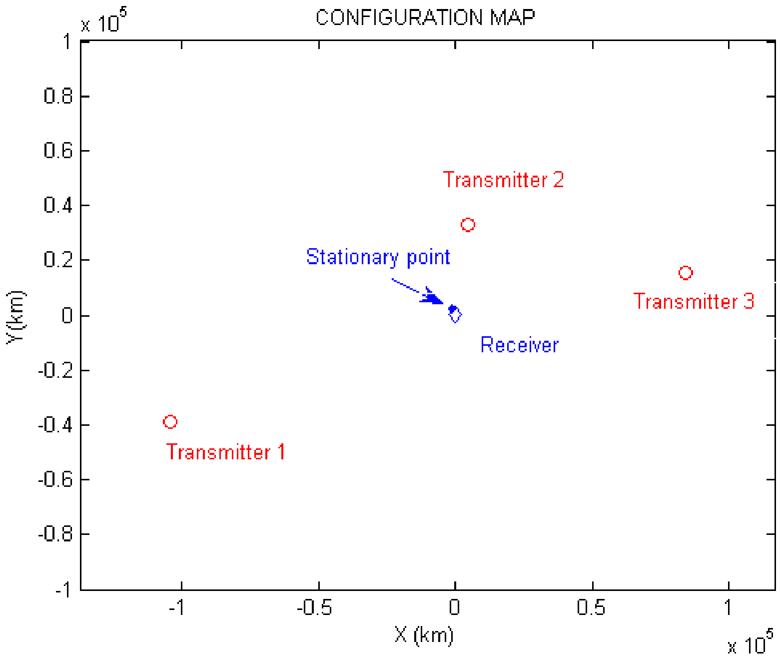

Figure 3-2: configuration map

3.2 UAV detections in multiple bistatic configuration (including SFN)

The following results are corresponding to :

- A frequency carrier working in SFN mode between Transmitter 1 and Transmitter 2
- A fixed wing UAV achieving "periodic circular patterns"

It has to be noticed that the delay between transmitter 1 and 2 is not only the geographical one : from a strict geographical point of view transmitter 1 is at longer range that transmitter 2 while it arrives first on the receiver due to the additional delays (or advances) that DVB-T broadcasters are adding to their system components in SFN mode.

In order to simplify the figure interpretation, only the plots within the expected (range, angle) domain of the UAV have been represented.

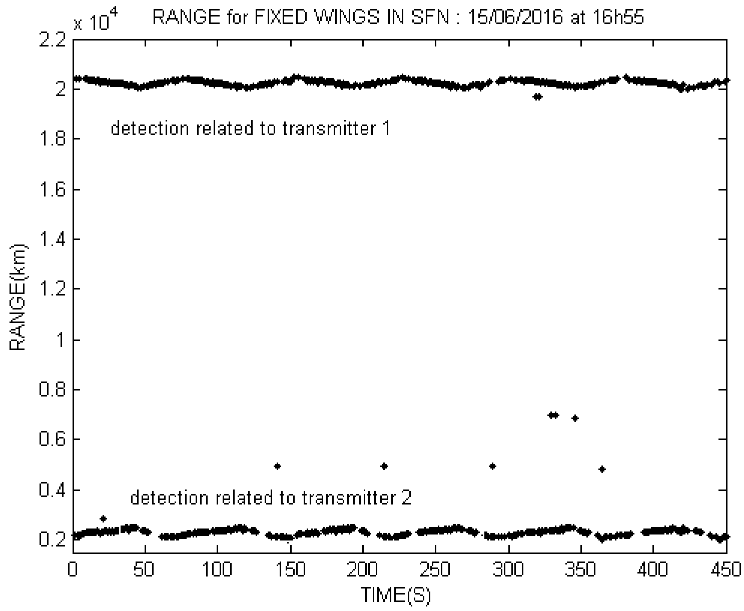

Figure 3-3: UAV range along time for the two SFN transmitters (1 close to 20 km and 2 close to 2.4 km the figures are bistatic ranges)

For the next figure, it is important to notice that the angle represented versus time is the superposition of the two previous ranges for transmitter 1 and 2 : it is just a reception angle and consequently it is not dependant on the transmitter that ensures the UAV detection.

For this angle, the GPS truth has been superimposed in red color.

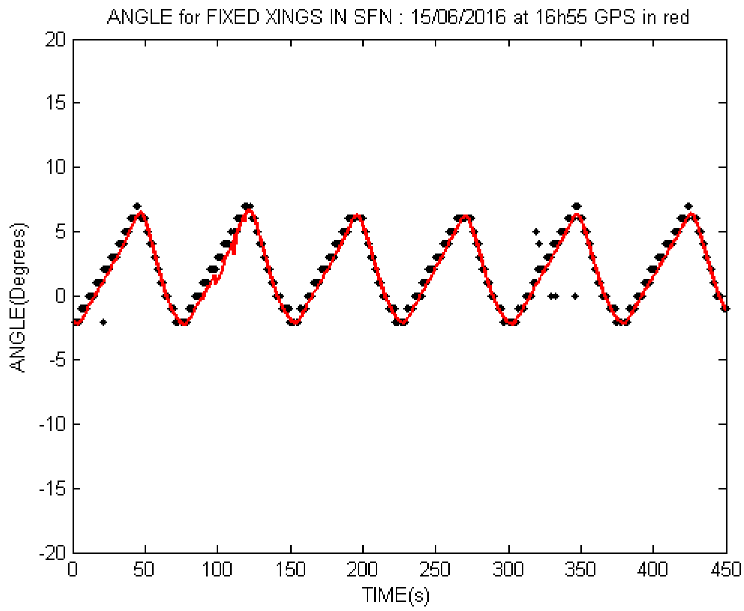

Figure 3.4: UAV azimuth along time for the two SFN transmitters (1 and 2) compared with the GPS truth

3.3 Location capabilities using a single bistatic base

The next figure is corresponding to the detection of a stationary multirotor using the transmitter 3 :

The represented plots have been “filtered” by keeping only those whose range is close to the stationary point. The blade modulation is clearly detected while the UAV itself (like in the previous stationary example) is not detected due to its “zero-Doppler” behaviour..

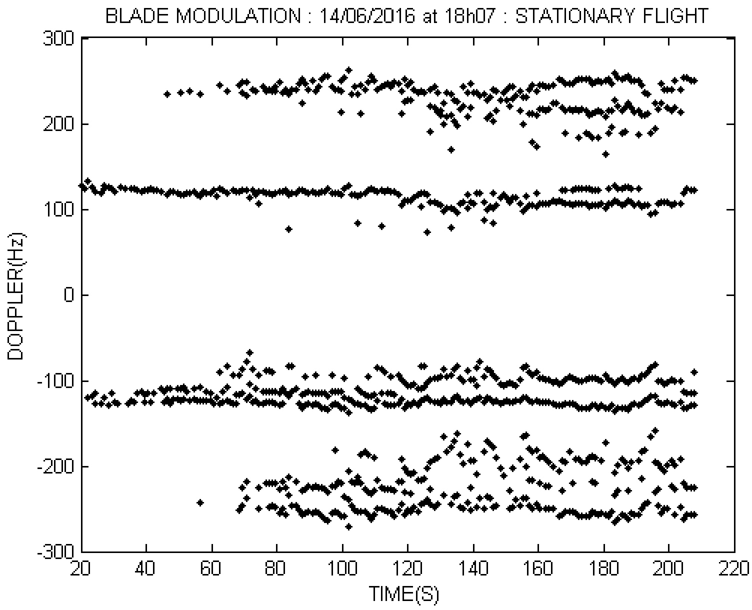

Figure 3-5: blade modulation (stationary multirotor at roughly 3 kilometres form the receiver) with transmitter 3

The next figure represents the location of this stationary multirotor using the bistatic configuration with transmitter 3. The Cartesian coordinates represented are simply obtained by considering the equation between the bistatic range and angle measurement and the Cartesian coordinates. As time is not considered in such an expression, the result is referred as location and not tracking. For comparison, the results obtained for a fixed wing UAV achieving circles in the vicinity of this stationary point have been superimposed

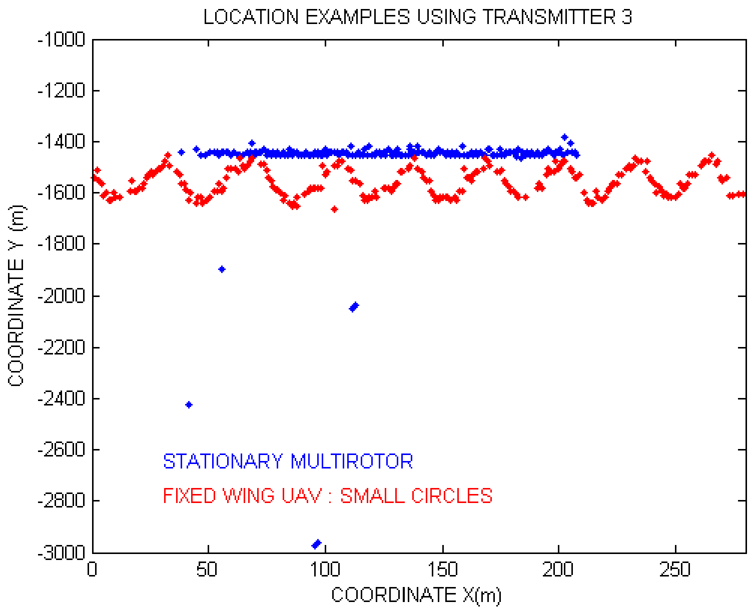

Figure 3-6: estimated X coordinate (stationary multirotor at roughly 3 kilometres from the receiver (blue) and fixed wing UAV in circles (red)) with transmitter 3

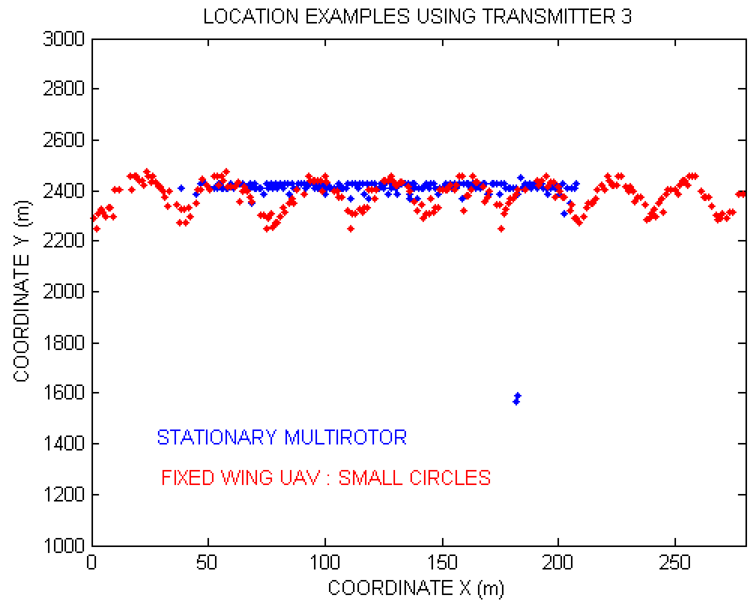

Figure 3-7: estimated Y coordinate (stationary multirotor at roughly 3 kilometres form the receiver (blue) and fixed wing UAV in circles (red)) with transmitter 3

The last following figure represents an example of Cartesian coordinate's restitution still using a single bistatic base but in another configuration (different receiver and transmitter locations) for which we had the ground truth (represented in red). The good correspondence between the estimated location and the ground truth tends to consider that a bistatic tracker could be sufficient for a good localisation of the UAV if we except the degenerated situation such as the targets close to the bistatic axis.

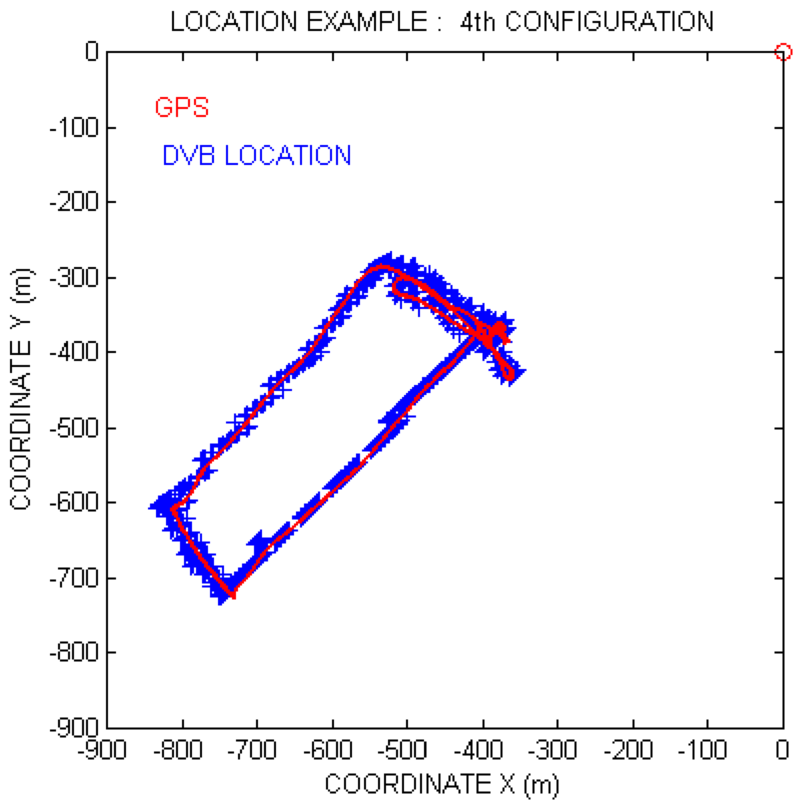

Figure 3-8: estimated coordinates (UAV in blue) versus GPS truth (red).

4.0 CONCLUSION

This paper has presented an overview of the main capabilities of a passive DVB-T component against UAV. The main advantages of such a passive DVB system against illegal UAV flights are :

- The blade modulation detection
- The multistatic detection (even in SFN configuration)
- The accurate UAV location even using a single bistatic base (under not degenerated configuration).

All these advantages have been illustrated using experimental results.

According to these results it is also possible to imagine the following DVB solution enhancements :

- The UAV tracking even using a single bistatic base
- Some UAV discrimination capabilities (from the other mobile targets) with the help of the blade modulation effect.

Most of these results have been obtained during the ANR ANGELAS which is one of the French Projects for struggling against illegal UAV flights.

Bibliography

[1] Kuschel H. “approaching 80 years of passive radar” IEEE Radar COnf, Adelaide, Australia 2013, pp213-217

[2] “Special issue on passive radar systems” IET Radar Sonar Navig, june 2005, volume 152 issue 3

[3] D Poullin “passive detection using digital broadcasters (DAB, DVB) with COFDM modulation”.

IET Radar Sonar Navig, june 2005, volume 152 issue 3

[4] Colone F, Falcone P, Bongioanni C et al “WiFi based passive bistatic radar data processing schemes and experimental results” IEEE TAES 2012 volume 48 issue 2 pp1061-107