TECHNICAL EVALUATION REPORT
MSG-SET-183 Specialists' Meeting on "DRONE DETECTABILITY: MODELLING THE RELEVANT SIGNATURE"

Held Virtually (via WebEx) on

Tuesday 27th April 2021, 14:30-17:50 (Time are in CET (GMT+1)

Wednesday 28th April 2021, 14:30-17:50 (Time are in CET (GMT+1)

Thursday 29th April 2021, 14:30-17:50 (Time are in CET (GMT+1)

Prepared by Alfonso Farina
Selex-ES (retired), LFIEEE, FREng, FIET, F-EURASIP, EurASc, Real Academia de Ingenieria
IEEE AESS, Board of Governors, Editorial Board of IEEE SP Magazine

alfonso.farina@outlook.it

INTRODUCTION

The MSG was originally planned in presence in October 2020 together with "Future Forces Forum" in Prague (http://www.future-forces-forum.org/?lang=en).

Then due to pandemics, the meeting was rescheduled in person to April 2021, and again rescheduled on line maintaining the planned date of April.

The meeting motivations are based on the following.

The proliferation of small UAS platforms (sUAS), which includes the former known as Low, Slow and Small (LSS) within the NATO UAV Class 1, flying singularly or in large formation (e.g. swarm of drones), brings with it a rapidly evolving threat for national defence and security agencies in various and challenging new scenarios. Thus, next generation defence systems must be designed to face such threats. A proper system design should start from an adequate modelling of the context and simulation of the system behaviour.

One of the most challenging aspects is the capability to model the threats, both from signature and behaviour points of view. Models will be used only for analysis and design of Counter sUAS systems, starting from simulation in a full synthetic environment.

The capabilities of detection of small UAS are generally affiliated with one or more of their attributes, which have very small radar cross sections, very low thermal signatures, are potentially camouflaged to visible cameras, low/no-acoustic signature, very few metal components, automated with limited to no human control.

The ability to detect these UASs is strongly related to multiple detection technologies to be integrated or fused into a single detection/classification architecture to ensure higher probability of detection.

The objectives of this Specialists' Meeting is to understand the requirements that have to be met by a drone detection system with respect to the drone characteristics that constitute the sUAS signature.

MEETING THEME

The Specialists' Meeting has been considered into four themed Sessions as described below:

1) **Current Detection Technologies - Experiences and Challenges with Modelling sUAS Signatures**

   Countering small Unmanned Aerial Systems is not a new challenge and detection solutions are already available on the defence market. Experiences from the development of these systems should give an insight into the complexity of sUAS characteristics and the challenges arising when defining the relevant signatures of these systems to enable reliable detection methods.

2) **Recent Developments and Future Threats – Anticipated Challenges for Modelling sUAS Signatures**

   Technology is developing rapidly, in many cases, faster than the defence industry or NATO can react. Therefore, traditional signatures may be inappropriate to support detection of future sUAS. Furthermore, new technologies such as the fifth generation cellular networks, may allow for concealing the signature of electromagnetic emissions of the Command and Control link inside the network.

3) **Modelling the Relevant Signatures for 'Traditional' Detection Methods**

   We can assume that detection methods utilizing 'traditional' signatures such as, e.g., radar, EO/IR, or acoustics will still be relevant in the future. UAS, no matter how small, will still have to obey the laws of physics and emit traceable signatures in the electromagnetic spectrum. Therefore, it is important to identify those parts of the spectrum (EM, RF, Acoustic, Thermal, etc) where sUAS provide their most prominent signatures.

4) **New Approaches for Modelling the Relevant Signatures to enable Future Detection Methods**

   Currently fielded detection methods for sUAS may reach their limits if new technologies are applied. Future sUAS may be even smaller, faster and less visible than today. Autonomy and Artificial Intelligence may significantly reduce or eliminate active transmissions from and to the air vehicle. Hence, signatures of sUAS may be more difficult to track and even incapable on their own to reliably

The presented 23 papers map on the above mentioned four themed Sessions of the Specialists' Meeting as follows.

1) Current Detection Technologies - Experiences and Challenges with Modelling sUAS Signatures related papers: 2, 4, 5, 7, 10, 11, 12, 13, 14, 18 and 19. These refer to bistatic radar (at DVB-T and WIFI), time-frequency analysis of received radar signal, micro Doppler signature for target classification, identification and discrimination from natural and man-made disturbances, multispectral detection, multispectral multisensory drone signatures, etc.

2) Recent Developments and Future Threats – Anticipated Challenges for Modelling sUAS Signatures related papers: 15. Exploitation of flight path curvature to distinguish/classify drones from birds.

3) Modelling the Relevant Signatures for 'Traditional' Detection Methods related papers: 1, 3, 6 and 20. These refer to high-detail simulation of UAV RCS signatures exploiting full wave e.m. solvers, CAD models, and comparison with measurements in anechoic chambers and outdoor on turn table

and during UAV flights. Modelling and classification of EO signatures, Modelling and classification of telemetry data.

4) New Approaches for Modelling the Relevant Signatures to enable Future Detection Methods related papers: 8, 9, 16, 17 and 21. These refer to acoustic signatures, virtual microphone signals of flying drones, audio sensor networks, and also FHSS communication links.

To be noted that the keynotes K1 and K2 have mostly addresses all the Symposium themes.

About 200 pages of compiled papers and related slides in power point is the tangible bonus of the initiative. In addition, having a lively Q/A sessions among the experts who have attended the Specialist meeting increases the knowledge and share the expertise on the “Drone Detectability: Modelling The Relevant Signature” in the NATO Community.

The number of Attendees has been quite high and about constant across each day, and from day to day.

- Tuesday 27th April 2021: number of attendees, 118,
- Wednesday 28th April 2021: number of attendees, 104,
- Thursday 29th April 2021: number of attendees, 94.

In the following, a summary of each presentation is enclosed.

DAY 1: TUESDAY 27TH APRIL 2021

Introduction

The Chairman, Dr Paolo Proietti, began the work with a warm welcome to the Attendees and recalling the Call for Paper (see the Annex 2). The Chairman then introduced each speaker spelling her/his name, the organisation of origin, a short CV, and the title of the talk. At the end of each speech, Dr Proietti asked for questions from the attendees. These questions arrived via chat and/or virtually rising the hand. The colleague asking the question was unmuted and reply came consequently. At the end of each speech, virtual applause appeared on the PC screen.

Keynote #1: Rob Olthoff: “Counter Unmanned Aerial Systems (UAS) Threats”

Very authoritative and highly informative. The key note vividly set up the scene of the MSG_SET-183. The author describing the UAS incidents in the years 2018, 2019, 2020 and 2021. Classifying the UAS threats in Civil domain (Methods, Vital Infrastructures (mainly fixed locations), Events), and Military (Asymmetric conflict, Symmetric conflict with high intensity). The classification of UAS followed the NATO UAS Classification guide. The challenges to contrast the threat are related to the speed of technological developments (Swarm & Swarming - Independent Operation / Navigation, Stealth, Deconfliction: X-mas present, pizza or terroristic attack, Development opponents).

Paper #1-Francesco Fioranelli: “Improving the simulations of radar signatures of small drones”

This paper presented initial results of the simulator of radar signatures of small drones flying individually or as a swarm, currently developed at the University of Glasgow in collaboration with TU Delft. The simulator is capable to generate radar signatures of different models of drones flying in arbitrary trajectories and mimicking different operational parameters of realistic radar systems. Although the electromagnetic fidelity of the drones’ signatures can be improved, these initial results showed good agreement between simulated data and experimental data obtained from two radar systems. The value of the simulator lies in the possibility to model radar signatures for different drones, radars, and scenarios to complement experimental data and to help development of tracking, classification, and situational awareness algorithms.

Paper #2-M. Pilar Jarabo-Amores: "Modelling of Drone Bistatic RCS Fluctuations for UHF Passive Radar Scenarios' Simulation"

The presentation tackles the modelling of Bistatic Radar Cross Section (BRCS) fluctuations generated by geometry variations along targets' trajectories. Main objectives are to approximate real use cases in radar scenario simulations, and to study BRCS fluctuations potential value for extracting targets' classification features in UHF Passive Radars. Different drones and trajectories are considered, and two methodologies are proposed and validated using real data acquired by IDEPAR (Improved DEtection techniques for PAssive Radars) demonstrator: target BRCS estimation from CAF (Cross Ambiguity Function) data; interference estimation at CAF level using spatial filtering. Results demonstrate the suitability of the proposed methodologies for radar scenarios simulation and their potential use for targets' modelling and feature extraction.

Paper #3-Peter Speirs: "High-detail simulations of UAV RCS signatures, and comparisons against measurements"

There is a comprehensive comparison – encouraging and successful - between the simulation (using full-wave solvers – either FEM – Finite Element Method - or MoM – Method of Moments, supported by simplified CAD – Computer Assisted Design - models) of RCS of UAV (multirotor, Skywalker X8 flying wing, quadcopter) and the measurements of such UAV in an anechoic chamber with radar at X-band (frequency range 5.8 to 17.5 GHz). Direct comparisons of measured RCS values, their histograms, means and variances as a function of sensor incidence angle have been achieved. Tests whether the measurements could be embraced in the classical Swerling modes were attempted. In addition, ISAR and micro Doppler measurements where shown.

Paper #4-Pavel Sedivy: "Drone RCS statistical behaviour"

The paper presents the results of the measurement of nano and micro size drones RCS. The measurements were collected in an anechoic chamber using the far-field setup in X-band, and by means of a vector network analyser with time-domain post-processing. Drones include quad-copters, hexacopters and fixed-wing 2 m wingspan glider. The collected measurements of RCS were displayed results in the form of RCS azimuth polar plot, statistics and cumulative density function (vs. RCS, sqm) curves for different observation angles in azimuth and elevation. The final aim is to support the evaluation of detection performance and provide cues for automated target recognition (i.e. exploit RCS frequency fluctuations for target classification – distinguish groups of targets according to size).

Paper #5-Duncan A. Robertson: "Study of radar signatures of drones equipped with threat payloads"

The article studies the effect on the radar signature of payloads embarked on drones. Two 24 GHz and 94 GHz radars are used. Experimental measurements show that the Doppler signature is useful to help classify the type of payload.

Suitable signal processing techniques are used (for signals with variable behaviour in time and frequency), such as: STFT (Short Time Fourier Transform), SVD (Singular Value Decomposition) and Continuous Wavelet Transform (CWT). Figs 11 and fig 12 of the article show results that show the change in the signature of the echo signal appropriately processed in the presence and absence of payload. The analysis is interesting and can facilitate the automatic classification that indicates the type, presence, and time of release of the payload. The article and presentation are impeccably written and have a high professional level, both mathematical and engineering.

Paper #6-Pascale Sévigny: "Unmanned Aircraft (UA) GPS telemetry data for track modelling and classification"

The paper offers alternatives to the exploitation of micro-Doppler signatures and of the range-Doppler matrices of detection data for Unmanned Aircraft (UAs) classification. The focus of the article is on tracking of UA so far not covered in previous presentations.

The authors explore the use of readily-available Global Positioning System (GPS) telemetry data that can be downloaded following a UA flight. UA telemetry data are used as the basis for radar detection and tracking simulations, and for trajectory investigations. A radar detection and tracking simulation framework is presented. Trajectory features (Table 1 with Feature definition is quite interesting) are defined and preliminary track classification results are presented. The end goal of the research is to develop a radar track classifier, which would enable UA identification at longer ranges, which implies automated clutter mitigation for limiting the number of false radar cues.

A better understanding and characterization of typical trajectories of varying UA types for ultimately classifying UAs based on their radar tracks, is also sought. The GPS telemetry data set was further analysed for trajectory features to distinguish between rotary-wing and fixed-wing UAs. A key point to tackle in future study is whether the UA classifier is to be trained on raw GPS data only or combined with simulated radar track data. The ultimate goal is to obtain a robust classifier to predict UA class of real experimental radar track data.

Paper #7-Stanislava Gazovova: "UAV detection by Micro-Doppler Signatures Application"

The paper applies the formula of the e.m. scattering of a rotating blade - for the continue wave (CW) radar - to the micro-Doppler signature of UAV rotors.

Calculations of Receiver Operating Characteristics (ROC), i.e. detection probability, versus the probability of false alarms for assigned values of the signal to noise ratio (SNR) are provided for Swerling 1 model. Detection probability of a specified amount of micro Doppler signature (i.e.: mean power of the signal corresponding to the reflection of the UAV rigid body, compared with the mean power of the signal corresponding to the reflection of UAV rotating parts) is also provided. Based on the abovementioned e.m. scattering model, the paper shows the simulation of micro-Doppler signatures, and compares them with measurement performed with K-band CW radar. To be noted: the micro-Doppler signature of each UAV rotor typically changes differently and non-periodic due to different rotations. This will imply the use of time-frequency analysis tools for target classification.

DAY 2: WEDNESDAY 28TH APRIL 2021

Introduction

The Chairman, Dr Paolo Proietti, began the work with a warm welcome again to the Attendees for this second Meeting day. As in the previous day, the Chairman then introduced each speaker spelling her/his name, the organisation of origin, a short CV, and the title of the talk, and invite attendees to ask question by means of the Chat box at the end of each speech.

Keynote #2-Jacco Dominicus: "Keynote 2: New Generation of C-UAS to Defeat of Low Slow and Small (LSS) Air Threats"

Key Note 2 is an extensive, comprehensive and first-hand review of the expected features of C-UAS second generation systems resulting from the findings of three year work of the NATO SCI-301 Research Task Group (RTG). The SCI-301 was subdivided into four teams: (A) Threats Horizon Watch, Operational

Analysis and Modelling & Simulation, (B) Novel Detection and Identification, (C) Future Effectors, and (C) Networking and Autonomy. Example of commercial drones as a threat have been reported by Team A, together with vignettes to protect a notional base.

The process of countering LSS air threats is depicted in Figure 4. The paper provides a detailed description of methods for Prevention, Detection, Tracking, Classification, Identification & Intent. Interesting is a list of all the “abilities” the system should have: to reliably detect, to accurately track, to classify and identify, to determine intent, to locate and identify the operator, to disseminate the information to a human being, to integrate the detection system in a wider context, to do all of the above in a timely manner, to do all of the above for multiple drones, to do all of the above in various weather conditions, to do all of the above with limited manpower.

A review of the existing methods of detecting LSS air vehicles are also briefly reviewed: Passive RF, Active RF, Acoustic detection, EO/IR, LiDAR, and Exotic sensors.

The process of Decision-making is next described. The relevant information for decision making include: What type of LSS air vehicle is it? What is the intention of the drone? Does it pose an immediate threat? What is its intended target? Who operates the drone? Where is it operated? How many contacts are detected? Is it likely that more (undetected) drones are in the air or will be deployed? What is the most likely course of action when no intervention takes place? Which effectors are available for use? What is the preferred achievable effect? What is the most likely result of our intended action? What will be the adversary’s response to our action? What is the risk involved with the proposed intervention?

Then the “Intervention” process is tackled. Here an incremental list of reactions: Ignore, Monitor, Deceive, Coerce (Deter, Compel), Distract, Disturb, Delay, Deny, Take over control, Capture, Neutralise, Degrade and Destroy.

Team C made a list of effectors (also on the basis of previous NIAG studies): RF Jamming, RF Spoofing, GNSS Jamming, GNSS Spoofing, Nets, Jet streams, Projectiles, Lasers, High Power Microwaves, High intensity ultrasound, Birds of prey. Finally, Forensics focusses on the collection, preservation and analysis of evidence relating to a C UAS situation, for example to determine the sequence of preceding events, identify the responsible entities and/or determine a modus operandi.

The key note concludes with reflections on the first generation (the current one) and the 2nd generation of C-UAS systems in terms of: Datalinks, Detection, tracking and identification, Preparation, Decision support, Interoperability and integration, Effectors, Cost effectiveness, DEW, Saturation, Point defence, defence at range and area defence, Hunter-killer drones, Training, Upgradability, Research, development and production, and Acquisition processes The ultimate goal being the “deterrence”.

Indeed a precious key note paper.

Paper #8-Kurt Heutschi: “Virtual microphone signals of flying drones”

This article deals with the possibility of exploiting the noise produced by the drone to detect its presence and track it. An interesting analysis of the acoustic spectrum produced by the drone is also presented. It would have been interesting to know what is the distance at which the drone can be detected as a function of the emitted noise and of the operational environment. The Authors plan to exploit the study results of the data recorded in the experiments to assess whether a human being may be able to hear and detect it by noise!

The practical applicability of this acoustic system for drones entails that the battlefield or the area to be monitored is covered with a network of acoustic sensors and then the recorded signals are sent to a C2 where there are operators who can give the alert.

Paper #9-James Stephenson: "Acoustic signature measurements and modelling of sUAS vehicles"

This paper models and measures – with an extensive wind tunnel test campaign - the acoustic signature of a small UAS in several configurations: with and without two upstream wing, a range of propeller revolution rates, yaw angles and wind tunnel speeds. The acoustic detection calculation method is based on the human aural detection model described in the literature (U.S. Army Human Engineering Laboratory, March, 1985) and ISO R-226 (1961). The calculation also accounts for three configurations of ambient noise levels. The experimental data proves that full vehicle aerodynamics are required to predict acoustic detection metrics for UAS vehicles. In fact, the upstream bodies provide a tactically significant increase in acoustic emissions of the vehicle.

Paper #10-John Chadwick: "Micro-Doppler Detection of Small UAVs"

This paper shows how to exploit the micro Doppler signature of rotor or propeller blade rotations of small UAV to help distinguish them from birds, wind-farms and ground vehicles. For target classification the authors recommend to use the time-frequency distributions, such as the Wigner-Ville Distribution (WVD) and Hilbert-Huang transform (HHT), in contrast to long and short window spectrogram and subsequent post-processing. They also consider the different contributions from amplitude and phase modulation in the data and its relation to viewing aspect.

Experiments have been performed on laboratory and field trials of grounded and airborne UAV. Simulations and experiments (with over 23 figures collected in the paper) have suggested that amplitude modulation is primarily responsible for the micro-Doppler lines. This originates from blade flash in the in-plane case and from shadowing, polarisation or multipath in the perpendicular case. Micro Doppler spectrum aliasing should be mitigated by suitable choice of radar PRF.

Future work will imply features extraction, by training and testing with a broader range of simulated and real data. The needed SNR for robustness to noise and reliable classification is another point for in depth investigation.

Paper #11-Benjamin Knödler: "Passive Sensor Processing and Data Fusion for Drone Detection"

To detect and track micro drone, the project described in the article employ four types of sensors (providing related measurements). (i) Passive Coherent Location (PCL) Radar: bistatic range, bistatic range rate, and azimuth, (ii) RF (Radio Frequency-emitter localization techniques): Azimuth, (3) Acoustics: Azimuth, Elevation, (4) EO / IR: Azimuth, Elevation.

Interesting is the description and application of the Track-before-Detect (TbD) Particle Filter for PCL. The TbD method applied on the bistatic measurements aims to detect and track the reflection of an UAV in this measurement domain. This avoids nonlinearities introduced by the transformation to Cartesian space.

The fusion engine combines the UAV observations from the various sensors and provides the results to the command and control centre in real-time to enable instant response capabilities. Each sensor component provides processed observations in the form of a target information vector to the fusion centre.

The conclusions of the article are important and point to the deployment of systems with multiple heterogeneous sensors. The MHT (Multi Hypothesis Tracker) algorithm was developed and applied to the multisensor case.

Experimental results supported these conclusions. Of interest is, in fact, Figure 20, with the following caption: Fusion Engine results: Track initialization with radar (a), Track refinement with RF (b), Track refinement with EO/IR sensors (c), Track continuation after flying through the sensor shadow (d).

Paper #12-Miroslav Krátký: "Commercial UAVs Multispectral detection"

The article describes a multisensory-multispectral approach for detecting small-sized drones. The integrated system may offer more chances for prompt, sufficiently accurate, robust and reliable detection of minidrones. The Fig 17 (Overview of the results of the performed experiments) summarizing the sensor performances is excellent. The article describes a comprehensive experimental campaign and testifies several years of research to support the design of future defence and protection systems against UAS threats. A design guideline is system modularity. The experimentations confirm a detection area of up to 2000 m and a terminal area of up to 300 m around a guarded location. These are tips for sensor network installation and for the use of counter UAS equipment - effectors.

Paper #13-Stanislaw Rzewuski: "Drone detectability feasibility study using passive radars operating in WIFI and DVB-T band"

The PCL radar exploiting the DVB-T and WIFI signals as transmitters of opportunity were used to detect the small size Parrot AR Drone. PCL can be safely installed for surveillance in urbanized areas.

Two experiments have been conducted and their results show that both signals WIFI and DVB-T can be used for drone detection. Experiments have been performed in two different locations.

The first experiment exploited a purposely-built WIFI network to conduct the experiment. The distance between the WIFI nodes and radar antennas & receivers was between 100-200 m. Experiment shows that it is possible to detect small size Parrot AR drone on bistatic distance equal to 50m.

The second experiment was performed near a city. The DVB - T illuminator was located at 45 km from the receiver (radar) location. The drone was detected at the bistatic range of 200m. Future work will combine in one system the capability to exploit both WIFI and DVB-T signals. Range resolution is different, around 7.5m for WIFI based and 30m for DVB-T. In addition, range cover is greater in the DVB-T than WIFI. DVB-T can cue the detection to WIFI for better location accuracy at shorter range.

Paper #14-Michael Caris: "UAV Detection in Millimetre Wave Radar Bands"

For radar operation in urban area and with surveillance distances up to several hundreds of meters, millimetre-wave and sub-millimetre-wave (35 GHz, 94 GHz, 210 GHz, or 300 GHz) systems may be advantageous. (i) Multireflections are cancelled out by physical effects of the rough surface that is important between buildings surrounded by asphalt. (ii) Micro-Doppler of the minimal movements of UAVs leads to an easily measurable frequency-shift. (iii) These frequencies are affected by a minimum atmospheric attenuation. (iv) Very compact and lightweight radar sensors can be realized with wide signal bandwidth to provide fine range resolution. (v) These millimetre wave radars have low power consumption and are characterized through a better target-to-background ratio than classical radar bands. (vi) The antenna size together with the aperture angle is small and the antenna gain is high. (vii) Stand-off detection of dangerous materials like explosives and signature analysis of Doppler or radar cross section of targets is possible.

The radar was designed and the main radar components were developed and assembled. The system estimates target range by means of FMCW frequency measurement, the radar cross section (RCS) via the reflected energy corrected by the range as well as azimuth, which is measured by rotating the radar front-end. The radial target's velocity is calculated from the Doppler effect, by means of cross-range Fourier transformation.

Static measurement have been done in an anechoic chamber using a network analyser, looking to the UAV at different aspect angles. Two different UAV types were anlysed. The RCS of the objects is evaluated in the field via turntable measurements in a distance of about 140m. Turntable allows also high resolution measurements of the targets by the inverse SAR method (ISAR).

The RCS measurement of a flying drone was attempted the pointing the radar beam to the flying drone. These measurements were also performed versus time, thru the correlation between the radar data and INS (on board of the drone) data.

DAY 3: THURSDAY 29TH APRIL 2021

Introduction.

The Chairman, Dr Paolo Proietti, began the work with a warm welcome again to the Attendees for this third and last Meeting day. As in the previous days, the Chairman then introduced each speaker spelling her/his name, the organisation of origin, a short CV, and the title of the talk, and invite attendees to ask question by means of the Chat box at the end of each speech.

Paper #15-Iraj Mantegh: "Detection and classification of drones and birds at a far distance using radar data"

Both birds and small drones fly at low altitude, with low speed and have small size. To discriminate drones from flying birds, this paper investigates on the measurement of the flight curvature of drones and compare it with that of birds. The latter have the ability to manoeuvre more. Therefore, the authors take flight curvature as a feature to distinguish drones from birds.

The method proposed for classification uses features from interactive multiple models (IMM) tracking filter together with flight trajectories that uniquely describe the flight of each target (bird and small drones as well). The basic set of motion models in the IMM tracking filter includes the Constant Velocity (CV), Constant Acceleration (CA), Horizontal Coordinated Turn (HCT) and 3D Coordinated Turn (3DCT) and few more, which can accurately represent target manoeuvres. The purpose of the IMM tracking is twofold: (i) to improve the tracking accuracy and (ii) to adopt the bank of motion models to classify the targets at ranges greater than 500m.

The authors have analysed the variation of speed, acceleration, and curvature of the flight trajectories during relatively straight and turning segments. As shown in Table 2 of the paper, there is a significant difference among the distribution of these parameters for the bird and drone flights. This is due to the inherent difference in the kinematics of their flights.

Synthetic tracks have been generated for flying pigeon's and drone (Phantom-2) by exploiting some GPS data (in the case of pigeon, trajectories were recorded at high resolution at 5 samples/sec by miniature GPS devices). The dataset contains 11 free flights of the flocking birds and 11 free flights of the drones, each flight with an average duration of 75 mins and 20 mins respectively.

The synthetic tracks were injected into three classifiers: (i) Naïve Bayes (NB), (ii) Kernel Support Vector Machine (K-SVM) and (iii) Decision Tree. The Table 4 in the paper shows the accuracy of the three classifiers in the case of GPS and synthetic data; achieved results are promising.

Paper #16-Vincent van der Knaap, "Detection and characterization of a UAS RF FHSS communication link"

Frequency Hopping Spread Spectrum (FHSS) is one of the main communication techniques in use by UAS. This communication system can be detected and its parameters identified. In fact, the Authors report that from the analysis of the recorded uplink signal segment, the FHSS signal can clearly be observed.

After ADC, the down converted FHSS signal model is expressed as a matrix linear equation which contains the following unknown parameters to be estimated: (i) Carrier frequency (e.g. 2.4 or 5.8 GHz); (ii) Total signal bandwidth, (ii) Dwell-Time, (iii) Central frequencies of each hops, (iv) Hopping pattern. The presence of discontinuities in the signal in a low SNR environment makes the estimation a challenging task. Improving the robustness of detection, even for high noise levels, is essential for real world implementation of a FHSS detection algorithm.

The FHSS is detected and the parameters estimated with suitably refined wavelet based (i.e.: Daubechies mother wavelet) signal processing techniques. The algorithms have been tested on numerical simulation as well as experimental results on commercial DJI Phantom 2 drone.

Application to larger data sets was also shown. Table 1 in the paper shows promising results in terms of probability of detection as a function of the SNR.

Interestingly, by exploiting multipath information, estimated using oversampling, a single sensor becomes capable of differentiating between multiple sources. The information obtained from this analysis can be used for the benefits of various Counter Measures (CM), such as: (i) Smart/Adaptive Jamming; (ii) Demodulation of the link and allowing for communication takeover; (iii) Attribution of transmitted data, such as location of the detected UAS.

Paper #17-Sachin Shetty: "Machine Learning Empowered Radio Frequency Signal Classification for UAS Detection"

The signal emitted by the drone is received, its properties are estimated (e.g.: modulation) assuming that the signal is cyclostationary and therefore signal processing techniques developed for this type of signal can be applied, and the class of the drone is identified to some extent.

In the case of several UAS and complex operational situations, Machine Learning techniques are presented for the "automatic" recognition of signal modulation.

Experiments have been carried out in three test sites with Clear Line of Sight, as well as Shadowing/Fading, by using the same experimental setup (with software defined radio technology and suitable directional antenna) and testing protocols and amount of collected data. The drone is the DJI Mavic 2 UAS. The initial experimental result have shown that the setup systems and related algorithms are able to detect presence of drone signal successfully in presence of varying SNR regimes. Future work will continue to focus on multi-UAS classification.

Paper #18-Alexander Borghgraef: "SET-260: A Measurement Campaign for EO/IR Signatures of UAVs"

This paper describes a remarkable work that shows the cooperation between 11 R&D and governmental entities from 9 Nations. It refers to the NATO Research Task Group SET-260 aimed at bringing together experts in EO/IR detection to share detection knowledge and signature data of mini and micro UAVs in an urban environment. A NATO joint trial was organized to collect UAV EO/IR signatures of UAVs in different bands with an urban background.

A joint trial was organised at the simulated village of Joeffrécourt in the French Armed Forces urban training facility, CENZUB in June 2019. The drones in the trials are: DJI Phantom, Parrot Anafi microdrone, Parrot Disco fixed wing UAV, Modified DJI S900 hexacopter and DJI Matrice 100 quadcopter.

The partners from the nations brought a wide array of EO/IR sensors to the trial positioned in various locations to acquire a range of fields of view. The bands covered in the trial were the following: (i) UV: 200-300nm, (ii) VIS: 400-700nm, (iii) NIR: >700nm, (iv) SWIR: 900-1600nm, (v) MWIR: 3-5µm, (vi) LWIR: 8-12µm, (vii) Hyperspectral: 400-1700nm.

From the initial reporting it is clear that active imaging systems, both gated imaging and LiDAR systems, have a remarkable potential for the application of UAV detection. When such a laser-based system is unavailable due to cost, complexity, laser safety or tactical stealth requirements, the experience shows that using multiple bands is a necessity, since different material backgrounds for the UAV will provide different contrasts in for example MWIR and LWIR, making it impossible to say one always outperforms the other. This trial resulted in a vast amount of data that is still being processed. Future work included the annotation of the data collected in order to facilitate the development and validation of automated detection and tracking algorithms using a machine learning approach.

Paper #19-Guillaume Gagné: "Electro-optical and RF sensors assessment in counter unmanned autonomous vehicle context"

Canadian Armed Forces is facing the threat related to UAVs. Defence Research and Development Canada was committed to evaluate the performance of EO and IR systems to detect, recognize, identify, and track (DRI&T) micro and mini Class 1 UAVs and to propose enhancements to the capacity of these systems.

Optical and radar systems have been used for DRI&T. The set of optical cameras (called Automated Light EXperimental Imagery Systems (ALEXIS)) are in the Visible band (Vieworks VC-4MC-C180, Prosilica GC1020, Manta G-235C), in the (Short Wavelength Infrared - SWIR (Goodrich SU640HSX), in the Medium Wavelength Infrared – MWIR (FLIR SC6000, IRC 900), and in the Long Wavelength Infrared – LWIR (Sofradir Atom1024). ALEXIS is controlled by in-house software, the Versatile Tracking System which allows adjusting the camera settings, recording data and controlling the pan & tilt based on tracking algorithm results. Automatic tracking algorithms allowing camera selection and AI-based automatic detection and classification methods are currently integrated to the system to support the operators and to ease their work.

The radar sensor is an in-house millimetre-wavelength radar operating in 94-95 GHz (W band) with a FMCW modulation. The system is equipped with two antennas with an overall field of view of 3 degrees. This system provided a range capability up to 1 km with a range resolution better than one meter. Radar and optical cameras are installed on a joystick controlled pan & tilt platform mounted on a leveled tripod at 1.5m from the ground and it covers pan and tilt angles of 180 and 80 degrees respectively.

A variety of natural and man-made targets (referred to as confusers) can generate false alarms. Therefore, two campaigns were conducted (Fall 2018 and the Spring 2019) during the migration of snow geese to build a signature database (optical and radar).

A wide dataset collection experiments was conducted in Canada from 2017 to 2019 and under the NATO SET-260 (described in other papers of the MSG-SET-183).

Two radar classification algorithms were tested using the Range-Doppler imagechip signatures. (i) the HOG (Histograms of Oriented Gradients) suitably updated to classify UAVs against confusers such as birds. (ii) The MatlabTM Neural Network toolbox composed of seven layers (Image Input, Convolution, Batch Normalization, ReLu, Fully Connected, Softmax, Classification Output).

Optical image classification algorithms used publicly available neural networks called drone-net. Details on the implementation are in the paper.

Radar classification results were presented for the two radar classifiers. The HOG classifier has been characterised by the Confusion matrix to distinguish drone against bird; the achieved results appear excellent, and similarly for the Deep-Learning classifier.

To evaluate object detection with optical images, the most common metric is the mean Average Precision (mAP), which is retrieved by computing the area under the curve of the Precision-Recall curve. Table 5 in the paper gives the average results on five sampled test sets of the 2020 Drone-vs-Birds Challenge. Technical details are in the paper also concerning known and unknown sequences of data and the related processing time for their classification.

Future works will focus to assist operators often overloaded with data. Valuable information could be missed by the operator due to sloppiness, tiredness, or even to a lack of time due to operational constraints. This is why, in parallel to the UAVs signature acquisition, scientists at DRDC are working at the development of automation tools and AI technologies to assist and to augment DRI&T capacities of the operators. Future works are then concentrated toward this objective. In addition, the processing algorithms will be improved to deal with high cluttered condition, such as urban and low elevation conditions.

Paper #20-Garik Markarian: "Fully Automatic Electro-Optical Drone Detection System"

The author quoting his very recent book: G. Markarian, A. Staniforth. "Counter-Unmanned Aerial Vehicle Handbook". ARTECH House, USA, 2020, states that currently there are over 200 companies worldwide, claiming to have products and solutions for drone detection and neutralisation systems.

Concerning definitions related to C-UAV system, it is interesting to quote "Classification" (i.e.: ability to distinguish drones from other types of objects - like birds etc) and "Identification" (i.e.: ability to identify a particular model of the UAV, including type of payload, identify the drone's or controller's digital fingerprint, like a MAC (Media Access Control) address and pilot's location. This level of identification is essential for forensic and prosecution purposes.

Then a novel fully autonomous Electro-Optical drone detection system is presented, that implements the detection, classification and localisation of drones with no operator involvement. A hardware/logical scheme of the proposed EO system is depicted and described, together with the Detection Camera Module, Dispatch and Control Service (DCS), the Recognition Camera Module (RCM) and the EO Interface. In an experiment it is shown that the camera is following the moving drone. A RCNN (Recurrent Convolutional Neural Network) architecture is shown, where the input image is processed by a convolutional sequence of layers, producing a feature map. Next, a region-proposal sub-network is used based on the extracted features. After that, obtained region proposals are classified using the features within the region proposals.

Quoting from reported results : typical detection range for DJI Mavic and Phantom drones (around 30 cm x 30 cm) is in excess of 1.5 km in daytime conditions, while classification range with simple PTZ (Pan/Tilt/Zoom) camera (30 times zoom) is in excess of 1 km. The detection of drones with EO sensors greatly depends on weather conditions and visual appearance of the drone on the background. Night-time detection and classification strongly depend on the specific characteristics of the drone. Some challenges refer to the classification of wing-type drones, which are not well distinguishable. The quality of the classification algorithm significantly depends on the drone, which is classified. The drones like Inspire are easily classified due to their well-distinguishable visual appearance. Drones like Mavic are less visible, and in some poses are seen on the frame just like black blobs with no specific shapes. Thus, the requirement on the training data set is unbalanced: meaning that a longer training data set is needed for Mavic than for Inspire.

Future work will seek to improve the reliability of wing-type drones classification, night-time detection and classification.

Also future work will address the integration of side sensors to reduce the false-positive rate of the integrated system and allow detection of targets at poor visibility conditions.

Paper #21-Claudio S. Malavenda: "A Cooperative Time-Frequency Approach to Detect, Recognize and Track Drones with Audio Sensor Networks"

The presentation investigates the feasibility and proposes a solution to detect, recognize and track mini and micro UAS based on a three-layer algorithm and the use of an integrated wireless sensor network with on board audio sensors. It describes and verifies simulations for low power detection algorithms and signature-based characterization with audio data from real field.

CLOSING REMARKS

The MSG-SET-183 has been successful notwithstanding the postponements due to pandemic. The decision to keep the MSG-SET-183 on-line has been wise. The participation has been quite remarkable along all the three days. The presentations have been of high quality both from the formal point of view as well as in the substance. All the speakers have done an excellent presentation work.

The on-line interaction, also via chat, and mute-unmute process for Q/A sessions have been carefully managed by the Chairman. Virtual applauses have been appreciated improving the on-line empathy. Photographs of the session attendees were also appreciated and reduced in a sense the "distance" between in-presence conference and on-line event.

The preliminary review cycle of all the submitted papers and subsequently of the draft presentations in power point has been a good way to harmonise the style and contents of each presented work. This, may be lengthy, review procedure has been kindly accepted by all the authors who carefully and on time implemented them.

In the closing remarks, the Chairman P. Proietti and the technical evaluator A. Farina, promoted and took part to the discussion and exchange of opinions among the Colleagues.

Therefore, warm thanks goes to all the authors for their precious R&D work and for their professionalism and diligence to share it in the community. Commendations are deserved and due to the NATO Staff for all the organisational work. The authority of the Chairman has been pivotal for such a successful event.

CONCLUSIONS

A take away message could be the following:

"To suitably guarantee drone detection, tracking, classification and identification in possibly all weather conditions and operational environments, it seems mandatory to conceive, design, implement, test and validate an integrated multi-sensor-multispectral system with mission learning aids in order to assist the human operators, thus mitigating their work load. The decision makers will take advantages of the robustness and reliability of the end-to-end system, thus achieving better detection, classification and identification probabilities, stability and continuity of the target tracks, with a high confidence level to decide the adequate reaction."

RECOMMENDATIONS

It is emerging the operational need of implementing a NATO wide counter-small UAS infrastructure, which will be the lower layer in the multilayer surface-based air defence. This includes the whole chain from the sensor to the effector. In addition, the operational rules and doctrines should be declined.

As a prerequisite, it has also emerged the need for an end-to-end modelling and simulation of both s-UAS and the counter system.

Authors have remarked the need for training and testing with a broader range of simulated and real data. This implies a lengthy and accurate work of annotation of the collected data to facilitate the development and validation of automated detection and tracking algorithms using a machine learning approach.

Authors have recommended that future works will focus to assist operators often overloaded with data, since valuable information could be missed due to sloppiness, tiredness, or even to a lack of time due to operational constraints.

In addition, future efforts should bring to the conception of new processing algorithms to deal with high cluttered condition, such as urban and low elevation conditions.

ENCLOSED:

ANNEX 1 - List of Acronyms

ANNEX 2 - Call for Papers for the MSG-SET-RSM 183

ANNEX 3 - Announcement of postponement of the FFF 2020 to a new date.

ANNEX 4 - MSG-SET-183 RSM Programme

ANNEX 5 - MSG-SET-183 RSM: Questions and Answers Session.

ANNEX 6 – MSG-SET-183 RSM Virtual Stage Picture

ANNEX 1 - List of Acronyms

3DCT	3D Coordinated Turn
ADC	Analogue to Digital Conversion
AM	Amplitude Modulation
CA	Constant Acceleration
CAD	Computer Assisted Design
COTS	Commercial Off-The-Shelf
C-UAS	Counter Unmanned Aerial Systems
CV	Constant Velocity
CVD	Cadence Velocity Diagrams
DEW	Directed Energy Weapons
DRI&T	Detect, Recognize, Identify, and Track
DVB-T	Digital Video Broadcasting-Terrestrial
EMD	Empirical Mode Decomposition
EMP	Electro Magnetic Pulse
EO	Electro-Optical
FEM	Finite Element Method
FHSS	Frequency Hopping Spread Spectrum
FMCW	Frequency-Modulated Continuous-Wave Radar
GNSS	Global Navigation Satellite System
GPS	Global Positioning System.
HCT	Horizontal Coordinated Turn
HERM	Helicopter Rotation Modulation
HHT	Hilbert-Huang Transform
HOG	Histograms of oriented gradients
HPM	High Power Microwave

IMM	Interactive Multiple Models
INS	Inertial Navigation System
IR	InfraRed
ISAR	Inverse SAR method
ISR	Intelligence, Surveillance, Reconnaissance
JEM	Jet Engine Modulation
K-SVM	Kernel Support Vector Machine
LiDAR	Light Detection and Ranging
LSS	Low, Slow and Small
LWIR	Long Wavelength InfraRed
MAC	Media Access Control
MHT	Multi Hypothesis Tracker
MoM	Method of Moments
MSG	Modelling & Simulation Group
MWIR	Medium Wavelength InfraRed
NB	Naïve Bayes
NIAG	NATO Industrial Advisory Group
PCL	Passive Coherent Location
PET	Passive Emitter Tracking
PM	Doppler-based Phase Modulation
PS-WVD	Pseudo-Smoothed Wigner Ville Distribution
PTZ	PAN/TILT/ZOOM camera
TFD	Time-Frequency distributions
RCNN	Recurrent Convolutional Neural Network
RCS	Radar Cross Section
RF	Radio Frequency-emitter localization techniques

RPAS	Remotely Piloted Aircraft System
RSM	Research Specialists' Meeting
RTG	Research Task Group
SAR	Synthetic Aperture Radar
SCI	Systems Concepts and Integration
SET	Sensor Electronics Technology
STFT	Short-Time Fourier Transform
STO	Science & Technology Organization
sUAS	small UAS
SVD	Singular Value Decomposition
SWIR	Short Wavelength InfraRed
TbD	Track-before-Detect
TFA	Time-Frequency Analysis
TFD	Time-Frequency Distribution
UA	Unmanned Aircraft
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VNA	Vector Network Analyser
WIFI	WIreless FIdelity
WT	Wavelet Transform
WVD	Wigner-Ville Distribution
YOLO	You Only Live Once

ANNEX 2 - Call for Papers for the MSG-SET-RSM 183

NATO MODELLING & SIMULATION GROUP (NMSG)
&
SENSORS & ELECTRONICS TECHNOLOGY (SET) PANEL

CALL FOR PAPERS

for the MSG-SET-RSM 183 Specialists' Meeting on

DRONE DETECTABILITY: MODELLING THE RELEVANT SIGNATURE

to be held in
Prague, Czech Republic
21-22 October 2020

DEADLINE FOR RECEIPT OF ABSTRACTS:

29th February 2020

This event is UNCLASSIFIED, open to participants from NATO Nations, EOP Nations, and Austria, Singapore, New Zealand

The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and Programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Groups are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information Specialists'. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists'' Meetings, Lecture Series and Technical Courses.

TECHNICAL PROGRAMME COMMITTEE

PROGRAMME CO-CHAIRS

Mr Paolo PROIETTI
Leonardo spa
Italy
Tel: +39 06 4150 4180
Email: paolo.proietti@leonardocompany.com

Dr Jan FARLIK
University of Defence, Brno
Czech Republic
Tel: +420 605 586 940
Email: jan.farlik@unob.cz

COMMITTEE MEMBERS

Major Josef CASAR
University of Defence, Brno
Czech Republic
Tel: +420 732 583 113
Email: josef.casar@unob.cz

Mr Guillaume GAGNÉ
Defence Research & Development Canada, Valcartier
Canada
Tel: +1 418 844 4000
Email: guillaume.gagne@drdc-rddc.gc.ca

Mr Ismail GÖKHAN DERE
Aselsan
Turkey
Tel: +90 312 592 6000
Email: igdere@aselsan.com.tr

LtCol Andre HAIDER
Joint Air Competence Centre
Germany
Tel: +49 282 4 90 2224
Email:

Mr Stefan NILSSON
Swedish Defence Research Agency
Sweden
Tel: +46 13 37 84 52
Email: stefan.nilsson@foi.se

Dr Vadim STARY
University of Defence, Brno
Czech Republic
Tel: +420 923 443 675
Email: vadim.stary@unob.cz

Dr Peter WELLIG
Armasuisse
Switzerland
Tel: +41 58 468 28 10
Email: peter.wellig@armasuisse.ch

Mr Utku YILMAZ
Aselsan Rehis
Turkey
Tel: +90 312 592 6000/824346
Email: utkuyilmaz@aselsan.com.tr

Ms Daniela DEIANA
TNO
Netherlands
Tel: +31 6 46 966 212
Email: daniela.deiana@tno.nl

Dr Ing Bruno DI MARCO
Studio BOM
Italy
Tel: +39 335 88 20 60 23
Email: bruno.dimarco@s3log.it

LtCol WRJ (Rob) OLTHOFF
Commando Landstrijdkrachten- Ministry of Defence
Netherlands
Tel: +31 493 59 87 01
Email: wrj.olthoff@mindef.nl

Dr Yiannis PAPELIS
Old Dominion University
United States
Tel: +1 757 638 6560
Email: ypapelis@odu.edu

Dr Sachin SHETTY
Old Dominion University
United States
Tel: +1 757 686 6233
Email: sshetty@odu.edu

Prof Dr Peter ZWAMBORN
TNO
The Netherlands
Tel: +31 88 86 638 30
Email: peter.zwamborn@tno.nl

NMSG & SET PANEL OFFICE- POINTS OF CONTACT

MSCO Executive
Cdr Santiago FERNANDEZ-DAPENA (ESP)
Tel: +33 1 55 61 22 90
Email: santiago.fernandez-dapena@cso.nato.int

MSCO Assistant
Mrs Renata JAPERTAITE
Tel: +33 1 55 61 22 94
Email: renata.japertaite@cso.nato.int

SET Panel Executive
LtCol Francesco Santoro (ITA)
Tel: +33 1 55 61 22 68
Email: francesco.santoro@cso.nato.int

SET Panel Assistant
Ms Illeana GANZ
Tel: +33 1 55 61 22 69
Email: illeana.ganz@cso.nato.int

Rationale

The proliferation of small UAS platforms (sUAS), which includes the former known as Low, Slow and Small (LSS) within the NATO UAV Class 1, flying singularly or in large formation (e.g. swarm of drones), brings with it a rapidly evolving threat for national defence and security agencies in various and challenging new scenarios. Thus, next generation defence systems must be designed to face such threats. A proper system design should start from an adequate modelling of the context and simulation of the system behaviour.

One of the most challenging aspects is the capability to model the threats, both from signature and behaviour points of view. Models will be used only for analysis and design of Counter LSS systems, starting from simulation in a full synthetic environment.

The capabilities of detection of small UAS are generally affiliated with one or more of their attributes, which have very small radar cross sections, very low thermal signatures, are potentially camouflaged to visible cameras, low/no acoustic signature, very few metal components, automated with limited to no human control.

The ability to detect these UASs is strongly related to multiple detection technologies to be integrated or fused into a single detection/classification architecture to ensure higher probability of detection.

Specialists' Meeting Topics

The objectives of this Specialists' Meeting is to understand the requirements that have to be met by a drone detection system with respect to the drone characteristics that constitute the sUAS signature.

The Specialists' Meeting will be divided into four themed Sessions as described below:

1) **Current Detection Technologies - Experiences and Challenges with Modelling LSS UAS Signatures**

   Countering small Unmanned Aerial Systems is not a new challenge and detection solutions are already available on the defence market. Experiences from the development of these systems should give an insight into the complexity of LSS UAS characteristics and the challenges arising when defining the relevant signatures of these systems to enable reliable detection methods.

2) **Recent Developments and Future Threats – Anticipated Challenges for Modelling sUAS Signatures**

   Technology is developing rapidly, in many cases, faster than the defence industry or NATO can react. Therefore, traditional signatures may be inappropriate to support detection of future sUAS. Furthermore, new technologies such as the fifth generation cellular networks, may allow for concealing the signature of electromagnetic emissions of the Command and Control link inside the network.

3) **Modelling the Relevant Signatures for 'Traditional' Detection Methods**

   We can assume that detection methods utilizing 'traditional' signatures such as, e.g., radar, EO/IR, or acoustics will still be relevant in the future. UAS, no matter how small, will still have to obey the laws of physics and emit traceable signatures in the electromagnetic spectrum. Therefore, it is important to identify those parts of the spectrum (EM, RF, Acoustic, Thermal, etc) where sUAS provide their most prominent signatures.

4) **New Approaches for Modelling the Relevant Signatures to enable Future Detection Methods**

   Currently fielded detection methods for sUAS may reach their limits if new technologies are applied. Future sUAS may be even smaller, faster and less visible than today. Autonomy and Artificial Intelligence may significantly reduce or eliminate active transmissions from and to the air vehicle. Hence, signatures of sUAS may be more difficult to track and even incapable on their own to reliably identify the threat. New approaches or a combination of already established approaches may provide an answer to this challenge.

This Specialists' Meeting should facilitate the information exchange on sUAS signature characterisation and related modelling through presentations on most of the above-mentioned topics from research and innovation points of view, including theoretical studies, and trials and experimentation, based on research combined with modelling activities.

The result is to improve the current studies on the subject and suggest areas for further NATO research activities as well as reinforce the links with military bodies in NATO in order to improve the capability to meet the identified requirements.

The main objective proposed is related to the capability that modelling will provide for testing and evaluating. The new Counter sUAS systems should support Nations and NATO embarking on a series of Programmes for developing and deploying appropriate defensive measures, in terms of detection, classification, tracking and neutralisation of current and future sUAS threats in a cost effective manner.

Prominent Leaders, contributors and representatives from the military, government, academia, and industry are expected to attend the Meeting.

CALL FOR PAPERS

The Programme Committee invites interested Specialists' to submit an **extended Abstract** (2 to 4 pages) addressing one or more the above-mentioned topics.

The selected Authors will be invited to submit a **full Paper** (8 to 12 pages).

Please send an electronic copy of the extended Abstract together with the completed Questionnaire (attached) to the Technical Programme Committee Co-Chairs (paolo.proietti@leonardocompany.com) and (jan.farlik@unob.cz) with a courtesy copy to the MSCO & SET Panel Assistants (renata.japertaite@cso.nato.int and illeana.ganz@cso.nato.int) by the deadline of **29 February 2020.**

The extended Abstract must include the following information, at the beginning:

- **MSG-SET-183 Specialists' Meeting on "Drone Detectability: Modelling the Relevant Signature"**
- **Title of the Paper**
- **Name of the Lead Author, followed by the names of the Co-Author(s) if any, and then Company/Affiliation, complete mailing addresses, telephone, fax and e-mail addresses**
- *Note: The proceedings will be* ***Unclassified/Unlimited (Public Release).***
- Please use the Details of Authors Form (ANNEX A). Submissions without name(s) and complete address of Author(s), or incompletely filled in Details of Authors Forms will not be considered.
- **The Abstract must also contain a declaration from the Author(s) that there are no restrictions regarding presentation neither during the event nor of the publication of the paper (as described in the Abstract) in the Meeting Proceedings.**
- **It is the responsibility of each contributor to fulfil the publication release requirements of his/her organisation/company and country and to obtain the mandatory Clearance of Abstracts, papers and presentations.** An **official** Clearance (Form 13) is mandatory in the United Kingdom and United States. Please contact your national PoC or the MSCO/SETs Assistant for further information and specific procedures.
- **US Authors and non-US citizens affiliated with a US organization must comply with US procedures**.

It is the responsibility of each contributor to fulfil the publication release and Clearance requirements of his/her organization/company and country to obtain **a Clearance of Papers** as needed. An official Clearance is mandatory in the United States (Form 13: attached at the end of this document) and there may also be a requirement in other countries to obtain Clearance for Unclassified Papers. For further information, Authors may contact any of the Programme Committee Members listed in this document or their National STO Coordinator. Please allow sufficient time for the Clearance to be issued before the deadline. In this case, the NATO classification of the Papers is "APPROVED FOR PUBLIC RELEASE".

The Programme Committee will select a number of Papers that are considered suitable for presentation at the Specialists' Meeting. Authors will be notified by the date indicated in the schedule whether or not their Papers are selected. Authors of selected Papers will also be provided with information in the Instructions for Authors, which contains detailed instructions for the final formatting, presentation, transmission, etc. of full Papers.

The time allowed for each presenter of a Paper is approximately 20 minutes. Equipment will be available for PowerPoint presentations. All Papers accepted for presentation at the Specialists' Meeting will appear in the Meeting Proceedings and be published electronically.

Please note that the Authors of Papers selected for presentation will not be financially supported by this Organization. Authors are responsible for their hotel and travel.

IMPORTANT DATES

29 FEBRUARY 2020	● **Abstract submission deadline**
30 APRIL 2020	● **Acceptance notification to the Authors** ● Authors to receive "Instructions to Authors" package from CSO ● Authors to start national procedure to obtain the Presentation/Publication Release and Clearance Certificate (Form 13) *(this document will be included with the "Instructions to Authors" package)*
30 JUNE 2020	● **Submission of full Paper** (electronic by e-mail (Word & PDF) ● Submission of Presentation/Publication Release and Clearance Certificate (Form 13) to CSO
30 SEPTEMBER 2020	● Submission of the Power Point Presentation
21-22 OCTOBER 2020	● **Specialists' Meeting Oral Presentation**

PAPERS and PRESENTATIONS

Approximately 15/20 full Papers will be presented at the Plenary Sessions, each Author is allocated 25 minutes, with usually twenty minutes for the presentation of the Paper and five minutes for discussion. All presented Papers will be published. They should be written and presented in English.

AGENDA

The Specialists' Meeting will be organised in accordance with the following tentative Agenda depending on the number of Papers accepted.

	DAY 1		DAY 2
9:00-12:30	Session 1	9:00-12:30	Session 3
10min	Introduction	10min	Introduction
20+5min	Presentation 1	20+5min	Presentation 1
20+5min	Presentation 2	20+5min	Presentation 2
20+5min	Presentation 3	20+5min	Presentation 3
30min	Coffee Break	30min	Coffee Break
20+5min	Presentation 4	20+5min	Presentation 4
20+5min	Presentation 5	20+5min	Presentation 5
20+5min	Presentation 6	20+5min	Presentation 6
30min	Session Discussion	30min	Session Discussion
12:30-14:00	Lunch	12:30-14:00	Lunch
14:00-17:30	Session 2	14:00-17:30	Session 4
10min	Introduction	10min	Introduction
20+5min	Presentation 1	20+5min	Presentation 1
20+5min	Presentation 2	20+5min	Presentation 2
20+5min	Presentation 3	20+5min	Presentation 3
30min	Coffee Break	30min	Coffee Break
20+5min	Presentation 4	20+5min	Presentation 4
20+5min	Presentation 5	20+5min	Presentation 5
20+5min	Presentation 6	20+5min	Presentation 6
30min	Session Discussion	30min	Session Discussion
			Closing Remarks

GENERAL INFORMATION

Classification

All material and discussion in this Specialists' Meeting will be UNCLASSIFIED, Releasable to Public.

In the case of CLASSIFIED information to be presented, a dedicated **Closed Session** will be organised.

Participation and Enrolment

You are welcome to attend and participate in the Meeting, even if you do not present a Paper. However, it is mandatory for all individuals to enrol online via this link: https://events.sto.nato.int Website enrolment will open approximately two months before the date of the Specialists' Meeting. A General Information Package with hotel and Meeting Site information will be available for downloading upon validation of your enrolment.

Language

Presentations and discussions will be in English.

Specialists' Meeting Site and Accommodations

The Meeting will be held at the PVA, Prague, Czech Republic, within the Future Forces Forum 2020.

There is no Meeting registration fee.

Attendees and accompanying individuals are responsible for their accommodation arrangements and any travel expenses.

Any questions on the technical aspects of the scientific Programme or the participation process should be addressed to the Specialists' Meeting Co-Chairs.

PUBLICATION OF MEETING PROCEEDINGS

Complete instructions will be sent by the SET Panel Assistant to the Lead Authors of the selected Papers who will be providing a full Paper. The Instruction to Authors package will provide in detail all requirements and deadlines for the preparation of the final manuscripts and presentations.

All Authors must provide the CSO with a final version of their Paper (PdF and source document in Word), in accordance with the aforementioned schedule, together with the Presentation/Publication Release and Clearance Certificate (Form 13). Please keep in mind that all Papers must be written and presented in English.

A week before the event, the CSO will pre-release the Papers on the STO website under the "Pre-Released" section of the "Reports" pages and they will remain as such until officially published. The final publication (Meeting Proceedings) will be at a URL address which will be provided at a later date to all validated participants enrolled on the website. This official reference of the Meeting Proceedings of this Specialists' Meeting will include the presentations, Papers, posters (if any), demonstration videos (if any), an Executive Summary, Abstract and the TER (Technical Evaluation Report). Please note that the CSO reserves the right to print in the Proceedings any Paper or material presented at the Meeting.

Any questions on the technical aspects of the scientific Programme, or the participation process should be addressed to the Specialists' Meeting Co-Chairs.

Questions on the administrative aspects or requests for further information on STO activities should be addressed to the NMSG and SET Panel Offices:

SECURITY LEVEL AND CLEARANCE FOR PRESENTATIONS AND PAPERS

This Meeting is NATO UNCLASSIFIED. However, it is the responsibility of each contributor to fulfil the publication release and Clearance requirements of his/her organization/company and country to obtain Clearance of Abstracts and Papers as needed. An official Clearance is mandatory in the United States and there may also be a requirement in other countries to obtain Clearance for Unclassified as well as Classified Papers. For further information, Authors should contact the appropriate Programme Committee Member listed in this document or their National STO Coordinator.

Thank you for your contributions which are very much appreciated by the NATO community.

FUTURE FORCES FORUM International Platform for Trends & Technologies in Defence & Security www.future-forces-forum.org

Prague, 1 October 2020

Announcement of postponement of the FFF 2020 to a new date

The international defence & security exhibition, expert panels and networking within the FUTURE FORCES FORUM 2020, originally planned for 21-23 October, will not take place this year due to the negative development of the epidemiological situation. After considering all the circumstances, this decision was made in accordance with the Ministry of Defence of the Czech Republic as the most important institutional partner of the FFF project.

At today's meeting with the Minister of Defence of the Czech Republic, it was decided to postpone the 14th FUTURE FORCES FORUM to 28-30 April 2021. With regard to the negative development of the epidemiological situation not only in the Czech Republic and the associated measures preventing or significantly restricting travel, personal meetings and the organization of mass events, we jointly concluded that under such conditions the successful course of all planned events is endangered and the usual high level of the FFF cannot be guaranteed.

Our main goal is the utmost and long-term satisfaction of all FFF participants. We firmly believe that this difficult decision will be widely understood and perceived as the right step, above all to protect the health of all participants, and to avoid inefficient costs due to constraints which unfortunately affect the level of participating official delegates, traders and experts, which is crucial for the successful course of the FFF.

We deeply appreciate the expressed support in these difficult times and we look forward to the opportunity to meet again in person.

Respectfully

Daniel Kočí
Managing Director

Adam Drnek
Executive Director

International Coordination Centre FFF
Progres Partners Advertising, s.r.o.
Opletalova 55, 110 00 Prague 1

info@future-forces-forum.org
www.future-forces-forum.org
www.NATOexhibition.org

DEFENCE | SECURITY | INTERNATIONAL ORGANISATIONS | GOVERNMENTS | INDUSTRY | R&D

ANNEX 4 - MSG-SET-183 RSM Programme

PROGRAMME

SPECIALISTS' MEETING on

DRONE DETECTABILITY: MODELLING THE RELEVANT SIGNATURE

(MSG_SET-183 RSM)

VIRTUAL Mode via WebEx

Time are in CET (GMT+1)

	Tuesday 27th April 2021			
	Session 1			
	14:30	Introduction		
K1	14:35	Keynote 1: Counter Unmanned Aerial Systems (UAS) Threats	Rob Olthoff	WRJ.Olthoff@mindef.nl
1	15:15	Improving the simulations of radar signatures of small drones	Francesco Fioranelli	F.Fioranelli@tudelft.nl
2	15:35	Modelling of Drone Bistatic RCS Fluctuations for UHF Passive Radar Scenarios' Simulation	M. Pilar Jarabo-Amores	mpilar.jarabo@uah.es
3	15:55	High-detail simulations of UAV RCS signatures, and comparisons against measurements	Peter Speirs	peter.speirs@iap.unibe.ch
	16:15	*Comfort Break*		
4	16:30	Drone RCS statistical behaviour	Pavel Sedivy	psedivy@retia.cz
5	16:50	Study of radar signatures of drones equipped with threat payloads	Duncan A. Robertson	dar@st-andrews.ac.uk
6	17:10	Unmanned Aircraft (UA) GPS telemetry data for track modelling and classification	Pascale Sévigny	pascale.sevigny@ecn.forces.gc.ca
7	17:30	UAV detection by Micro-Doppler Signatures Application	Stanislava Gazovova	Stanislava.Gazovova@aos.sk
	17:50	*End of Day 1*		
	Wednesday 28th April 2021			
	Session 2			
	14:30	Introduction		
K2	14:35	Keynote 2: New Generation of C-UAS to Defeat of Low Slow and Small (LSS) Air Threats	Jacco Dominicus	Jacco.Dominicus@nlr.nl
8	15:15	Virtual microphone signals of flying drones	Kurt Heutschi	Kurt.Heutschi@empa.ch
9	15:35	Acoustic signature measurements and modelling of sUAS vehicles	James Stephenson	james.h.stephenson@nasa.gov
10	15:55	Micro-Doppler Detection of Small UAVs	John Chadwick	Jchadwick1@dstl.gov.uk
	16:15	*Comfort Break*		
11	16:30	Passive Sensor Processing and Data Fusion for Drone Detection	Benjamin Knödler	Benjamin.Knoedler@fkie.fraunhofer.de

12	16:50	Commercial UAVs Multispectral detection	Miroslav Krátký	miroslav.kratky@unob.cz
13	17:10	Drone detectability feasibility study using passive radars operating in WIFI and DVB-T band	Stanislaw Rzewuski	srzewuski@rstechnologies.pl
14	17:30	UAV Detection in Millimetre Wave Radar Bands	Michael Caris	michael.caris@fhr.fraunhofer.de
	17:50	*End of Day 2*		
	Thursday 29th April 2021			
	Session 3			
	14:30	Introduction		
15	14:35	Detection and classification of drones and birds at a far distance using radar data	Iraj Mantegh	Iraj.Mantegh@cnrc-nrc.gc.ca
16	14:55	Detection and characterization of a UAS RF FHSS communication link	Vincent van der Knaap	vincent.vanderknaap@tno.nl
17	15:15	Machine Learning Empowered Radio Frequency Signal Classification for UAS Detection	Sachin Shetty	sshetty@odu.edu
18	15:35	SET-260: A Measurement Campaign for EO/IR Signatures of UAVs	Alexander Borghgraef	Alexander.Borghgraef@mil.be
19	15:55	Electro-optical and RF sensors assessment in counter unmanned autonomous vehicle context	Guillaume Gagné	guillaume.gagne@drdc-rddc.gc.ca
	15:55	*Comfort Break*		
20	16:10	Fully Automatic Electro-Optical Drone Detection System	Garik Markarian	garik@rinicom.com
21	16:30	A Cooperative Time-Frequency Approach to Detect, Recognize and Track Drones with Audio Sensor Networks	Claudio S. Malavenda	claudiosanto.malavenda@gmail.com
	16:50	Discussion		
	17:40	Closing Remarks		
	17:45	*End of RSM*		

ANNEX 5 - MSG-SET-183 RSM: Questions and Answers Session

This document summaries the Q&A Session held during the Specialists' Meeting after each presentation

K1. Counter Unmanned Aerial Systems (UAS) Threats - Rob Olthoff

Q1 - I have been told recently (but I confess, I have not checked the information on correctness) that a couple of years ago a jammer was dropped from a light airplane in the vicinity of an airport (UK) intended to jam Air Traffic Control. The light airplane is a bit cumbersome and I feel it as unrealistic actually in close vicinity of an airport though. However, I can imagine that using an UAV to deliver an ATC jammer could be an effective way to disrupt an airfield. What is your opinion on this civilian/military threat scenarios?

***A1**:*

Q2 - How much difficult is to launch and coordinate a swarm of uav?

***A2**:*

Q3 - Regarding deconfliction, do you think electronic ID (call signs) is an essential feature for the future of legitimate UAS usage?

***A3**:*

Q4 - What's the current solution to a situation, where an unidentified drone appears e.g near critical infrastructure?

***A4**:*

Q5 - Do you think the lines are bluring between COTS threats and small MOTS loitering munitions - hence C-UAS systems will need to deal with both COTS and MOTS and loitering munitions (with you did not mention)?

***A5**:*

Q6 - How important is it to classify the type of UAV that is attacking you?

***A6**:*

1. Improving the simulations of radar signatures of small drones - Francesco Fioranelli

Q1 – About MAVIC simulation, is it considering physical parameter such as dimension, weight, material, number of rotors and blades, etc. To model the drone signature?

***A1**: At the moment, in a simple manner, the drone is modelled as a series of scatter points to which we associate a RCS value drawn from a statistic distribution, and a kinematic model that describes its trajectory. Then the total signature is modelled by superposition. We are thinking of improving the EM fidelity in this regard, but we would like to keep the focus of the project more on the swarms' modelling and estimation of metrics for situational awareness, and be content with an OK rather than a perfect EM simulation.*

However, we would be very happy to see if some collaboration is possible with groups who have studied and presented better EM models (we saw some in other presentations at the event) and how these can be integrated into the simulator.

Q2 – Interesting approach to build a simulation environment. This may also be used to train future Counter UAV decision aid systems. My question is triggered by slide 9/15. I'm curious whether the simulation environment is planned to be augmented with the variations the different engines are driven from the flight control computer to compensate for, for example, variations in wind speed. I got triggered by the differences in slide 9/15 between sims and measurements. Are the differences caused bij corrections of the flight control computer in order to stabilize the platform? If so, I think that would be a worthwhile addition to the simulation environment. What are your thoughts on this?

***A2**: We are considering this, although we have not done it yet – at the moment the kinematic of the drone is still modelled in a simple way, for example with sinusoidal functions for the vibrations. Indeed adding the effect of wind-induced changes would be a nice addition, or more realistic changes in the rotation speed of the rotors during different movements.*

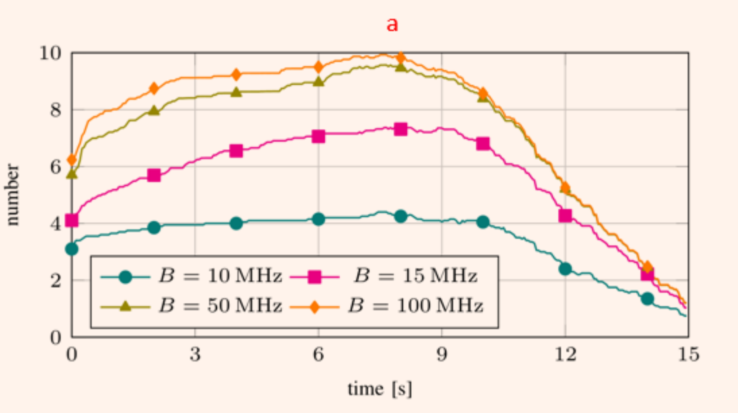
Q3 – A question related to 2nd presentation: does the model simulate 2D or 3D radars?

***A3**: The results shown in the slides at the event assumed a 2D radar scenario, but recent developments of the simulator enabled now the possibility of 3D simulations, hence being able to estimate the elevation of objects/drones as well.*

Q4 - What about resolution of radar in presence of small populated swarm of drones? and what about the extra SNR needed to do classification with respect to detection? thanks again.

***A4**: Very good questions!*

For the former, i.e. the resolution in case of a dense swarm, this is an aspect that we are exploring with an extension of the simulator, whereby some parameters can be changed for a given target or swarm to run a sort of Monte-Carlo test, or sensitivity test with respect to a parameter. We cannot provide as yet a number, but we aim to make the simulator capable to draw something like the below figure, where the number of detected individual drones over time as a function of bandwidth of the radar is given.



(a) Mean number of detected drones

For the second question on difference in SNR for detection vs classification, at the moment a very rough metric could be the difference in return for blades (assumed to be main source for classification) and body of the drone. We used some values from the literature for the difference blade vs body in RCS, but that is really hard to estimate (depending on drone models, materials of blades, etc) and it should rather being modelled statistically as some other presentations have shown at the event.

Another route that we are taking at the moment is to look more at "track-level" features which might not need blades signatures to perform classification (things like the velocity, trajectory, acceleration, altitude and their rates of changes). This is also something we saw with interest at the event.

Q5 - Can you expand on you investigation of thin wire model versus FEKO please?

A5: A little bit too long to answer this question in full details. I would suggest the interested readers to *refer to the two papers below and to the master thesis that was written by the student who worked on this model, which is available at the TU Delft repository.*

- *Y. Cai, O. Krasnov and A. Yarovoy, "Radar Recognition of Multi-Propeller Drones using Micro-Doppler Linear Spectra," 2019 16th European Radar Conference (EuRAD), 2019, pp. 185-188.*
- *Y. Cai, O. Krasnov and A. Yarovoy, "Simulation of Radar Micro-Doppler Patterns for Multi-Propeller Drones," 2019 International Radar Conference (RADAR), 2019, pp. 1-5, doi: 10.1109/RADAR41533.2019.171372.*
- *https://repository.tudelft.nl/islandora/object/uuid%3A2fe8fa3f-b4f9-45ea-a8c3-912aa433ba87*

2. Modelling of Drone Bistatic RCS Fluctuations for UHF Passive Radar Scenarios' Simulation - M. Pilar Jarabo-Amores

Q1 - Have you considered RCS as a function of velocity and altitude of the aircraft? If yes, are you able to comment on the properties?

A1*: Yes, we have. Presented results focus on drone trials which are really limited due to the necessity of asking for permission. But we have worked with other types if targets. As further distances are of interest, elevation incidence angles are close to 90º, but we have simulated different trajectories with constant altitude and velocities, and also trajectories with variable altitude. The analysis is simpler at high frequencies. In DVB-T we can be close to resonance, as in the presented results, and BRCS interpretation is more complex. Because of that simulation can be a useful tool.*

3. High-detail simulations of UAV RCS signatures, and comparisons against measurements - Peter Speirs

Q1 - How did you determine the real dielectric material parameters? My experience is that it is cumbersome to obtain the pertaining parameters.

A1*: By 'real' dielectric material properties I mean using estimates of the material parameters as opposed to just treating everything as PEC. To actually measure all of the necessary bulk material permittivities would be difficult, in part because this would ideally require quite large (relative to the components on the UAV) regularly-shaped samples to measure. However, for the UAVs that we have simulated it is fairly straightforward to say what material the different parts are made from in a coarse sense (copper, FR4, carbon fibre, plastic, rubber, polystyrene, etc.), and then use the material properties included in the Ansys HFSS libraries where available, or literature values and estimates where not. This is imperfect because even if we know, for example, that some piece of plastic is HDPE, the permittivity of HDPE varies between samples/manufacturers.*

In our model of the complex quadcopter we use a plastic hull with $\varepsilon = 3$, $\tan\delta = 0$; plastic rotors with $\varepsilon = 2.5$, $\tan\delta = 0$; and a copper wiring harness and motors with values from the HFSS materials library.

In the complex hexacopter model we use brass, copper, hard rubber, stainless steel and HDPE plastic from the HFSS materials library. For carbon fibre we use some values estimated from the literature: $\varepsilon = 5$, $\tan\delta = 0.8$, bulk conductivity = 52600 siemens/m.

In the complex octocopter model we use copper and stainless steel from the library, and the same values for carbon fibre as for the hexacopter.

For the flying wing model, from the library we use polystyrene, copper, FR4 and stainless steel. We also use a generic plastic with $\varepsilon = 2.5$, $\tan\delta = 0$ for the propeller.

It would probably make little difference if PEC were substituted for all the metals in the above cases.

In all of the simplified models we have assumed PEC, and a part of the point of the work has really been to demonstrate that a lot of the complexity likely in not really necessary to get good enough results. An extension of this argument is that, whilst it would be possible to have better values for the material properties, the likely benefit of doing so would almost certainly be very small.

Q2 - How many multiple bounces does the SBR solver use?

***A2**: The default value (at least in HFSS 19.5/2019 R3) is 5, which is what we use. We also leave the ray density at the default of 4/wavelength. For some other simulations we have experimented a little with increasing these numbers, but without ever seeing a noticeable difference in the results.*

Q3 - Swerling II model would involve a non coherent detection. any comment?

***A3**: Good point: I should clarify that what I mean is that the simulation and/or measurement RCS datasets have PDFs that are closer to either exponential (associated with Swerling case 1 and 2 models) or chi-square of degree 4 (associated with Swerling case 3 and 4 models). However, in computing or measuring the RCS values the incidence angles are varied over large ranges. Most of the models simulated were Swerling 1 or 2, but distinguishing between Swerling 1 and Swerling 2 would require knowing the decorrelation time, which will be dependent on the particular radar system, UAV, and the flight of the UAV, and is beyond the scope of the simulations. I would expect that in most real configurations the UAVs would actually behave more like Swerling 1 (decorrelated scan to scan) than Swerling 2 (decorrelated pulse to pulse) targets, in which case coherent detection would be absolutely fine, and indeed preferable.*

In other words, for small angular shifts in the incidence/scattering direction the signal will be more or less correlated. It is only for larger angular shifts that the decorrelation will be seen. Estimating decorrelation as a function of angle change is perhaps something I should look into, and should be possible with existing data. Thank you very much for the question.

4. Drone RCS statistical behaviour - Pavel Sedivy

Q1 - Based on your measurement, which parameter of UAV and radar has the biggest influence on the RCS (material, size, radar band, wave polarization…)?

***A1**: RCS of UAVs in average grows with UAV size. I would like to remark, that this growth of RCS stay in region of very small figures in general. No significant impact of material was fond, more significant impact was observed from design details (wires, electronics, batteries, ect). We are not able to describe impact of frequency band (all measurement was performed in X band). Measurement for VV and HH polarization was mostly close to each other, RCS for other polarization (circular and mixed) was not measured.*

5. Study of radar signatures of drones equipped with threat payloads - Duncan A. Robertson

Q1 - Is the SVD well conditioned?

***A1**: The degree of conditioning was different for different datasets but typically the conditioning number was always less than 100,000 (approximately ~75000 to ~80000).*

Q2 - Although in line with expectation, it is good to see that W-band radar performs better than K-band to detect spays. Just thinking, does increasing the wavelength (frequency) provide better performance? Or even go for optical sensors to detect sprays. What is your opinion on this?

***A2**: In general you will get stronger backscatter from liquid spray droplets at frequencies above W-band but the range performance is likely to be inferior. Active optical sensors like lidar may well detect liquid spray quite strongly, if they can be pointed in the right direction.*

6. Unmanned Aircraft (UA) GPS telemetry data for track modelling and classification - Pascale Sévigny

Q1 - For classification joined to tracking, did you try to exploit IMM?

***A1**: No, not yet. At the time of the study, the IMM tracker was not available in Stone Soup. But this is definitely in our future plans.*

Q2 - Is there some to win when using other sensor data?

***A2**: I believe there is much to gain in using other sensor data. We would like to provide classification information at longer ranges, even if classification is a little uncertain or incomplete (e.g. not a full identification). Other sensors could use this early warning and early classification to improve their own classification performance.*

Q3 - How might this approach cope with other small, slow flying objects like birds?

***A3**: The hope is to be able to distinguish between drones and other clutter at long ranges to decrease operator (or other sensor) overload. Studying bird data is very important. This is something we have started to study. We have found one dataset of bird GPS data. We will investigate this problem as a two-class (drone versus others) and three-class (fixed-wing, rotary-wing, other/bird) classification.*

Q4 - Can you explain the 9 features that was selected at the last phase? Are they all trajectory dependent (geometric, kinematic, etc) features?

***A4**: All the features are based on the raw x,y values of the trajectory data. We constructed 27 features such as min/max/mean/variance velocity, acceleration, curvature radius, etc. There are also geometric features such as the area of the minimum enclosing rectangle of the entire sub-trajectory. The features are listed in the paper and I can provide more details by email if required. We also selected 9 features that seemed more robust to transfer learning. They are typically mean values rather than minimum or maximum values. For example, a feature based on the maximum velocity is very sensitive to the noisy data, while the mean velocity is not.*

7. UAV detection by Micro-Doppler Signatures Application - Stanislava Gazovova

Q1 - Have you measured or simulated propellers RCS for considered/observed UAVs? Either absolute value or fraction of UAV's RCS?

***A1**: No, we haven't measured or simulated propellers' RCS.*

Q2 - Did you measure (consider) also coaxial settings of rotors (with push/pull propellers)?

***A2**: No, we didn’t.*

Q3 - How did 10^{-6} of Pfa was achieved?

***A3**: It is parameter defined by radar manufacturer.*

Q4 - Your time domain simulations show the blade flash lasts for a longer time if the blade length is longer which seems a little surprising - do you have measurements to confirm that?

***A4**: No, we don’t have any measurements for confirmation that, because we have only one appropriate model for measurements. The statement about blade flash duration is only from the simulation results.*

K2. New Generation of C-UAS to Defeat of Low Slow and Small (LSS) Air Threats - Jacco Dominicus

Q1 - Slide 9, I miss the iterative OODA loop structure. Is that on purpose? I mean that in that case the countermeasure must be "first time right". I think that to rely on "first time right" may be too optimistic an approach, even on the short response times available. Can you elaborate on your thoughts, please?

***A1**: Like any other process in the military, countering UASs obviously also follows the iterative OODA loop. Slide 9 however depicts the steps in the process of countering UASs. There is a relation between this* *schema and the OODA loop. The "Observe" phase of the OODA loop corresponds closely to the Detection/Tracking/etc. step of the scheme, although for example also the Forensic step includes observation. The "Orient" phase includes certain aspects of the Prevention step. In Boyd's view this phase in the OODA loop is more to do with training, experience and intellect of the humans involved. The "Decide" phase is closely related to the Decision Making step in the scheme, while the "Act" phase matches with the Intervention step in the scheme. The Forensics step is there among others to close the loop, since it includes Battle Damage Assessment (BDA). The result of which may for example have the operator decide to re-attack the UAS if needed.*

As for first generation C-UAS systems, if the UA poses an immediate threat, it will often come down to a "first time right" situation. Detection ranges of most of these systems are short, and so is the range of the effectors, which oftentimes just offer point defence capabilities. These combined with the typical approach speeds of UAs lead to only one chance of defeating the threat before it reaches its target. This is not a desired situation, that is the reason why more capable C-UAS systems are required. The ideal situation would be that enough time is available to escalate the effectors, for example by first trying to take over control of the UA by datalink spoofing, if that fails to proceed by jamming the datalink and if that fails to proceed with a hard-kill effector, such as smart munitions, a High Energy Laser (HEL), or a High Power Microwave. This would require the C-UAS system not only to detect and effect at longer ranges, but also to have multiple effectors available.

Q2 - You mentioned multistatic and passive radar as technologies of interest...do you see these a viable direction for counter-UAS?

***A1**: Definitely so, I feel that all modern detection techniques can contribute to detection of UASs at longer range, the possibility of classification and identification and the determination of intent. In addition, there is a requirement to reduce both the number of false positives and false negatives, as well as to be able to track multiple threats at the same time. All of this can be improved by having better and more sensors (to which multistatic and passive radar can contribute) and to have multiple types of sensors (e.g. combining radar with EO/IR sensors) by means of sensor fusing.*

A personal opinion on passive radar is that the concept has more merit when one controls the transmission of the radar signals, rather than when relying on an arbitrary donor radio broadcast.

Q3 - Nonetheless they fly short, in distance and duration and bring small payload. So we should exploit these deficiencies to our advantages, of course. Thanks for any comments.

***A1**: It is a true statement that small UASs do not offer all capabilities that larger airborne platforms can provide. However, it may not be wise to underestimate the capabilities of these platforms, as also indicated in Rob Olthoff's keynote speech. Some of these platforms fly higher, faster and farther than would be expected from their small size alone. Smaller payloads imply smaller sensors with less capabilities, or smaller lethality than larger explosive payloads. However, their numbers can compensate for some of these shortfalls. At the moment, UASs are more exploiting the deficiencies of the current C-UAS systems than vice versa.*

Comments:

Just to add to "air threats", a recent news article on unmanned boats as a threat: https://www.aljazeera.com/news/2021/4/27/saudi-arabia-says-it-foiled-boat-attack-off-yanbu-port

Another interested article: https://www.breitbart.com/border/2021/04/25/exclusive-photos-cartels-in-mexico-weaponized-drones-to-drop-ieds/

And another good summary here:

https://eandt.theiet.org/content/articles/2021/04/conflict-groups-arm-consumer-drones-to-deliver-death-and-terror/

8. Virtual microphone signals of flying drones - Kurt Heutschi

Q1 - The laboratory recordings will suffer from flow recirculation inside the laboratory significantly changing the acoustic emissions (20+ dB), especially at higher harmonics. How did you account for this in your measurements, and do you think that will affect your final conclusions?

***A1**: The effect of flow recirculation was not considered. The comparison of real (measured outdoors) and virtual (based on lab recordings) microphone levels did not reveal relevant differences, suggesting that the effect was not that important.*

Q2 - What causes the set of vertical lines in the spectrograms, please?

***A2**: This is sound of chirping birds. In the synthesis, background noise containing similar bird sounds was added to create a comparable soundscape.*

Q3 - Could you comment on the mitigation of reverberation from environment?

***A3**: Reverberation in the environment, e.g. in a street canyon, is simulated in the synthesizer by the superposition of specular reflections. An array based machine learning system to automatically detect drones that has a priori knowledge of the geometry of reflecting surfaces can possibly be trained to correctly distinguish between reflection images and original.*

9. Acoustic signature measurements and modelling of sUAS vehicles - James Stephenson

Q1 - Did you numerically solve the Navier-Stokes equations? In which operational conditions?

***A1**: The primary data came from a wind tunnel test in order to acquire validation data for aerodynamic and acoustic predictions. A very wide range of rotation rates, wind tunnel speeds, yaw angles, and wing configurations were captured. A full reporting of the test data is provided in the recent Vertical Flight Society proceedings (citation below), and can be provided upon request.*

Stephenson, J. H., Schatzman, N. L., Cheung, B. K., Zawodny, N. S., Sargent, D. C., Sim, B. W-C. "Aeroacoustic Measurements from the Aerodynamic and Acoustic Rotorprop Test (AART) in the National Full-Scale Aerodynamics Complex (NFAC) 40- by 80-Foot Wind Tunnel." Vertical Flight Society 77th Annual Forum, 2021.

The wind tunnel data was dependent on local weather conditions and was acquired over multiple months, especially thanks to COVID-19 related shutdowns. Wind tunnel speed was commanded based on Mach number, so each individual wind tunnel point accounts for local weather effects.

Q2 - What were the temperature and humidity conditions for the predictions?

***A2**: The MIL-STD-1474E assumes 15C and 70% humidity for propagation.*

10. Micro-Doppler Detection of Small UAVs - John Chadwick

Q1 - ML could have some chance because of image t-f

***A1**: Yes machine learning can be used here successfully by treating spectrogram or other TF plots as an image. We have applied various traditional and modern ML with good results since first writing the paper, but we are still actively working on ideas discussed in the paper.*

Q2 - Generally, micro-doppler radars acquired come with their own procession SW. Looking at your progress, I feel that we need raw data.

***A2**: We hope to modify existing software where possible. Secondly, we have now a great deal of raw data which we have been using to test algorithms and approaches.*

(captured by the Q&A moderator) Yes we gathered raw data and test various processing algorithms. They are working with academic to evaluate what is the best processing for drone classification.

Q3 - Did you consider wavelet transform?

A3*: Yes we have considered these but have not been found to be as useful as other approaches as regards classification. We are working on a range of feature extraction and classification algorithms. The ones shown in the paper are just 2 approaches amongst many, that we have considered, and seemed useful.*

(captured by the Q&A moderator) continue to work on feature extraction algorithm.

Q4 - Do your own analysis?

A4*: Not sure exactly what you mean but we or our contractors do processing and classification on the data.*

Q5 - Do you have a feeling of which techniques is more robust to the signature of the blades becoming weaker with distances?

A5*: This is a key question, we are still working on this but have some good ideas so far based on analysis is real data, but cannot share in this forum.*

11. Passive Sensor Processing and Data Fusion for Drone Detection - Benjamin Knödler

Q1 - What was conditions for acoustic detection experiment? I mean if there was night, silence, ...

A1*: The far-field measurements were achieved during the day (between 8h- 16h). We had good weather conditions (warm, sunny and not windy). Considering the fact that the experiment was conducted outdoors, the level of noise was low. However, it is possible to acoustically estimate the angular position of drones with the crow's nest array (CNA) under other conditions, i.e. under windy conditions with higher levels of noise.*

(captured by the Q&A moderator) It was during the day and other systems in the area. Cannot give the exact conditions for the measurement.

Q2 - In the video, it seemed that the measured track broke badly when the drone did a U-turn. Did all sensors fail there, or mainly some specific ones?

A2*: At the point where the track breaks off, the sensors were flown over almost directly (+/- 20m). The cameras are directional and have a maximum elevation of 60°, so the UAV could not be detected. The radar has an elevation of ~40° and the direction finder did not provide a reliable elevation, so the azimuth was ignored for close tracks to avoid false measurements during the overflight.*

(captured by the Q&A moderator) this particular video is not part of the actual project, only to show the operationality between the sensors.

Q3 - What was the level of the background noise during acoustic measurements? Thanks for the presentation.

A3*: The level of background noise during these acoustic measurements was low, i.e. there were almost no urban noises present and it was not windy. However, it is possible to acoustically estimate the angular position of drones with the crow's nest array (CNA) under noisy conditions, including scenarios with impulsive noises, speech, other motor noises or wind.*

(captured by the Q&A moderator) He will rely on the SME at Fraunhofer.

12. Commercial UAVs Multispectral detection - Miroslav Krátký

Q1 - Based on your experiments and considering, I think that we need to improve on a grid of sensors to get the "in depth detection" rather than to rely on one or a few sensors. What are your thoughts on this?

***A1**: Yes, that is the point. The best way, how to ensure all four periods of air space surveillance. i.e. detection, localisation, identification and tracking, is to establish a grid of sensors. This grid should to be based not only on the identical sensors disposed within area of interest in some logical configuration, but these sensors should respect primarily the probable air threat avenue approach, distance from the defended object and from effectors too.*

Moreover, this advisable grid should be – if possible – assembled from sensors working on principle more than one frequency band (in sense of radar, optical, IR, acoustic…).

13. Drone detectability feasibility study using passive radars operating in WIFI and DVB-T band - Stanislaw Rzewuski

Q1 - Do you have evaluated how the RCS would change with respect to different drone materials? (ref slides 11-13)

***A1**: No we have not focused on that part of the research. For us more important is the rough estimation of the RCS. We are more interested in the rough RCS of the drone to know if it is 0.02 m^2 or 0.5 m^2 and how it changes with the given passive radar frequency (DVB-T is signal is available at very different frequencies from around 300Mz to around 800MHz in case of Poland (year 2021)).*

Q2 - Regarding using Starlink 12-18 GHz signals, would it not be possible to have a low-cost downconverter and then use a cheap SDR on the IF?

***A2**: Starlink is using frequencies (according to Wikipedia) 12-18 GHz, 26.4-40 GHz and higher (like from 40GHz up to 90GHz). The idea of down-converter for various band is subject of future research. In case of Starlink Forward scattering might be a problem to be addressed (or ignored and assumed that system is "blind" when target flies between (in practice above) radar receiver and (under) Starlink satellite). But, if the radar will be flying above ground monitoring airspace (ground) below radar may solve this problem or even get rid of it.*

14. UAV Detection in Millimetre Wave Radar Bands - Stephan Stanko

Q1 - In the integrated RCS polar plots, the 210 GHz one looked smoother than the rest - why is that please?

***A1**:(captured by the Q&A moderator) That's right. This is due to numerical reading so its look more smooth, but it is creating*

Q2 - Multiple teams work with 94 GHz. Could dataset be shared with the community?

***A2**:(captured by the Q&A moderator) Yes this could be shared, but they have to identify the means to do it.*

15. Detection and classification of drones and birds at a far distance using radar data - Iraj Mantegh

Q1 - To measure and estimate the target Doppler acceleration you need a long time on target and high SNR. Could you be please to comment? Thanks.

***A1**: We do not measure the target acceleration from the radar signal, we calculate it based on the target position from the track. The radar used in our tests has an track update rate of 10Hz which is sufficient for our derivations.*

Q2 - You mentioned you used 21 features, do you have a feeling of whether they are all necessary or some are more effective than others?

***A2**: We combine kinematic and geometric features and we feel both groups are necessary. We think that the 21 features used here are optimum for our case (small UAS, small bird, ground object) classification. But we can reduce features if less variety of classes would be considered.*

Q3 - Do you think Doppler effect could be useful for the discrimination Drones/Birds?

***A3**: So, the radars used Doppler effect for tracking and detection. But due to the low RCS you may need Micro-Doppler for classification- please see the answer to Q4 for this.*

Q4 - Did you use micro-Doppler data into your classifier since you just talked about track data

***A4**: We did not use micro-Doppler in our classification, because our objective is classifications at higher ranges that current micro-Doppler can provide for.*

Micro-Doppler effect is helpful but the detection range is relatively low due to high power requirements. While it can improve at the current technology state, we have also experienced some ambiguities in the classifications, especially when you have more than multiple targets flying close to each other

Q5 - What do you think to be the best composition of systems to achieve good confidence level, while keeping cost as low as possible? Meaning of detection and classification only.

***A5**: We have used ESA Radar+ PTZ EO sensors with our AI Classifer and had relatively good success with the confidence level (~ 94% TP rate in sUAS classification). For night vision, IR can be added.*

Depending on the detection range of interest, you may be able to work with radar only and add Micro-Doppler and radar RCS information to have high confidence (and compensate for lack of PTZ).

16. Detection and characterization of a UAS RF FHSS communication link - Vincent van der Knaap

Q1 - Can you regularise the large matrix of data and keep up just the main eigenvalues and corresponding eigenvectors?

***A1**: Not in general, the large matrix does not have a low rank structure, in other words, it cannot be accurately represented by just the main eigenvalues and its corresponding eigenvectors. You would need to store a large amount of eigenvectors to represent the matrix which would defeat the purpose of trying to decrease the storage capacity needed. Unless you can show that it's eigenvectors are "sparser" than the original matrix, which is not necessarily the case.*

Comment:

This may be interesting in the context of this and the next presentation: We have recorded the RF control/video signals of some consumer drones and released the data to open access: https://doi.org/10.5281/zenodo.424639215:01

17. Machine Learning Empowered Radio Frequency Signal Classification for UAS Detection - Sachin Shetty

Q1 - The SNR seems with low numerical value. Classification – may be – would require some more SNR. Comments welcome.

***A1**: The platform is designed to work with low and high SNR. We used the adaptive energy detection to help us improve our ability to track low SNR. We are currently evaluating the eigenvalues based method would help us increase our ability to identify a clean signal. You are correct that the classification does* *depend on high SNR. So, the capability does very well with high SNR. However, we are required to detect the UAS at low SNR. So, given this requirement, we have to design the RF front end to address this issue.*

Q2 - The bandwidth problem of the USRP is an hardware related problem. I think that this can be solved by either choosing other hardware or start a dedicated SDR-implementation (appropriate ADC and FPGA platform). The same applies for the RF-front end. I think we can win a lot on this and the SNR. How do you envision that this may improve your results?

***A2**: Our requirement was to implement on COTS SDR, such as USRP B210. Given that the FPGA implementation for USRP devices lacks latest FPGA advancements, the performance does suffer. I agree that having a dedicated SDR implementation will address these issues. However, if organizations have a cost constraint and would like to best utilize existing USRP devices, then using them in a distributed setting can potentially address the accuracy issue. So, in summary, the choice is between distributed low cost USRP devices vs dedicated SDR implementation.*

18. SET-260: A Measurement Campaign for EO/IR Signatures of UAVs - Alexander Borghgraef

Q1 - Is there any follow on activity already planned within STO?

***A1**: The group had a 1 year extension for the organization of a second trial, but unfortunately the COVID crisis made that unfeasible. We are in the process of writing a TAP for a follow-up group to preserve the know-how obtained within SET260 during the CENZUB trial.*

Q2 - Can these Eo/IR sensors really compete with passive RF and radar for long range, wide area surveillance (detection and tracking of drones) or will they be better suited to follow-up ID?

***A2**: EO/IR has an advantage over radar in built-up areas, and it has no radio emissions, which may be necessary for tactical reasons. But indeed, surveilling large volumes is hard, and passive RF may be the better solution in most cases (with the exception of fully autonomous drones).*

19. Electro-optical and RF sensors assessment in counter unmanned autonomous vehicle context - Guillaume Gagné

Q1 - What was the input to your radar classifier **-** was it micro-Doppler spectrograms?

***A1**: The imagechips of the signature of the targets were extracted from the range-Doppler image. Each imagechip were compose of 9 x 9 pixels, 9 in the range axis and 9 in the Doppler axis. It seems the difference between the UAS and the bird signature is the Doppler signature close to the main body. The bird's wings produce low Doppler frequency.*

Q2 - Can you comment on the radar resolution and range of detection in your trial?

A2: The W band radar was operating with a range resolution of about 1m. The radar maximum range is in the order of 1 Km.

Q3 - More comments on Versatile Tracking Systems?

***A3**: Versatile Tracking System (VTS) is a DRDC’s in-house software. The VTS allows adjusting the camera settings, recording data and controlling the pan & tilt based on tracking algorithm results. Automatic tracking algorithms allowing camera selection and AI-based automatic detection and classification methods are currently integrated to the system to support the operators and to ease their work.*

20. Fully Automatic Electro-Optical Drone Detection System - Garik Markarian

Q1 - Impressive results! How does the system cope when the background to the drone is not sky but complicated terrain such as hillsides, trees etc.?

***A1**: as we do background subtraction and we use some improved algorithms, we managed to minimise the effect of background. It performs also the same as in uniform background. We have system installed in city centres. The bigger problem is direct sun light – for this we are using additional filters, which adds complications to the system*

Q2 - "AI Black box." Is it accepted by the customer?

***A2**: Yes, it is a product that we offer. So far, around 80 units were supplied to different customers. The "Black Box" is camera agnostic so potentially can be added even to the existing installation, bringing benefits of AI*

Q3 - I would like to buy this book **-** i see some amazon. is it possible to buy at the source?

***A3**: The book is published by ARTECH House. I sent E-mail with details directly to*

Q4 - Has your algorithm been tested using MWIR, LWIR or SWIR cameras?

***A4**: It was tested with IR, but not other cameras. Will be happy to test together*

21. A Cooperative Time-Frequency Approach to Detect, Recognize and Track Drones with Audio Sensor Networks - Claudio S. Malavenda

Q1: Can you comment on the use of Particle Swarm optimisation?

***A1**: It is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. It solves a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formula over the particle's position and velocity. Each particle's movement is influenced by its local best-known position, but is also guided toward the best-known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.*

Introducing following equation in a PSO algorithm

$$\begin{cases} x_i \in \mathbb{R}^n; & \vec{x_i}(t) = \vec{x_i}(t-1) + \vec{v_i}(t) \\ v_i \in \mathbb{R}^n; & \vec{v_i}(t) = \vec{I}(t-1) + \vec{M}(t-1) + \vec{C}(t-1) \end{cases} \qquad (1)$$

Where I is the inertia, M is the memory and C the expression of cooperation defined in following equations:

$$\begin{cases} \vec{I}(t-1) = \vec{v_i}(t-1) \\ \vec{M}(t-1) = \varphi_1 rand\left(\vec{p_i} - \vec{x_i}(t-1)\right) \\ \vec{C}(t-1) = \varphi_2 rand\left(\vec{p_g} - \vec{x_i}(t-1)\right) \end{cases} \qquad (2)$$

Whera in (2) φ_1 and $\varphi_2 \in \mathbb{R}^+$ are accelleration terms and „rand" is a random number generator in the interval $\mathfrak{U}[0.0; 1.0]$.

We can also identify $\vec{p_i}$ as the vector containing the best position values obtained during the evolution of the particle number ‚i' and $\vec{p_g}$ as the vector of the best global values obtained among all particles.

During the evolution for each particle we can identify

$$\begin{cases} p_{best} \equiv f(\overrightarrow{p_i}) \\ g_{best} \equiv f(\overrightarrow{p_g}) \end{cases}$$

Where $f(\vec{x})$ if the fitness function optimized.

Q2: I'm also thinking on relatively low-cost RF-sensor grid and I also see a problem with battery power. I think that adding a PV-module may mitigate this problem but not solve it. Have you considered this photovoltaic option? If yes, what was the reason to set it aside?

***A2**: We have tested some solutions based on supercapacitors and some type of energy crawler. The PV module was investigated some years ago, but was not easily combinable with the use case: sensors should be air-dropped and it would be not cost effective to integrate other electronics to discover the attitude of the sensor in order to enable a PV directed to the sun.*

Looking today at the evolution of PV, a new scouting should be conducted: the dimension and price of some small PV is compatible with the target price of the sensor. In the case of the audio-node a positioning performed by human operator could be implemented to avoid the orientation issue.

Q3 - Looking at low frequencies only might be challenging with respect to environmental noise that is usually strong at low frequencies. Could you comment on this?

***A3**: The user case identified in this self-financed article use audio recorded in a quite clean open field, also avoid this type of problem. It is not a really limiting assumption, because we assume that the main target for this technology is for border surveillance in remote regions not so noisy. Of course, if the target use case was a city, the problem approach should be quite different.*

I think that focusing on low-frequencies is the lead way for the discrimination of drone with only audio. However, in order to cope with more complex and noisier audio environment, the algorithm could be improved to discriminate the presence of base low frequencies and its harmonics. A big point we would, but we had not resources to analyse in this direction, is the use of cepstral analysis to capture the presence of harmonics into the audio spectrum and then use the base low-frequency to recognize the type of drone.

Open Discussion

I wonder what attendees consider to be the 'grand challenges' in the field for the next ~5 years? Fully autonomous, low latency C-UAS systems? The threat from swarms? Ever smaller, faster or even stealthy drones?

ANNEX 6 – MSG-SET-183 RSM Virtual Stage Picture