SET-260: A Measurement Campaign for EO/IR Signatures of UAVs

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ABSTRACT

NATO Research Task Group SET-260 aimed at bringing together experts in EO/IR detection among the NATO community to share detection knowledge and signature data of mini and micro UAVs in an urban environment. Within the program of work of SET-260, a NATO joint trial was organized to collect UAV EO/IR signatures of UAVs in different bands with an urban background. The trial took place in CENZUB, the French armed forces training center for urban combat, in June 2019. In this paper, we present details of this trial and discuss the challenges, pros and cons of detecting UAVs in the different EO/IR bands.

1.0 INTRODUCTION

The NATO SET-260 RTG aims at bringing together experts in EO/IR detection among the NATO community to share knowledge and data on different EO/IR technologies for the detection of mini and micro UAVs in an urban environment. A joint trial was conducted with different sensor systems and UAVs where measurements of UAV and background signatures were taken simultaneously in bands covering VIS to FWIR. The SET-260 UAV Measurement Campaign 2019 was conducted 8-13 June 2019 at the Center d'entrainement aux actions en zone urbaine (CENZUB) in France. CENZUB is an urban training facility for French armed forces located at Sissonne in north-eastern France. The signatures were shared among the nine participating nations to further be exploited to compare the performances of the different technologies and for the development and evaluation of detection and tracking algorithms.

2.0 TRIAL OVERVIEW

The objective of the trial was to collect UAVs and background signatures in order to determine the detection performances, capabilities, and limitations of the different EO/IR spectral bands and to trained detection and tracking algorithms based on artificial intelligence (AI).

The flight path and speed of the UAVs were known and were optimized to collect signatures at different aspect angles, with different backgrounds. The performances evaluation and comparison of detection and tracking systems were beyond the scope of the trial. Initial conclusions of the trial are that UAV detection and tracking in the urban environment is challenging and that there is not a single spectrum band that offers better performances against all observed background in the trial. Moreover, occlusion and reflection caused by man-made structures (buildings, vehicles, …) and natural environment (trees, hills, …) could add complexity to the detection/tracking problem. Finally, signature of birds can be similar to a UAV signature and could affect the false alarm rate of a detection system.

2.1 Trial site: Joeffrécourt-CENZUB

The Measurement Campaign was conducted 8-13 June 2019 in the Joeffrécourt area of the CENZUB training facility. Joeffrécourt is a replica of a typical European village (Figure 1). It includes a city center, residential neighbourhood, modern zone and an industrial zone. Given the limited amount of time available on-site, the trial schedule was limited to scenarios in the city center and the industrial zone, during the day and night. These choices were made to simulate the most likely targets for terrorist drone attacks: the dense population area of the city center and the concentration of chemical products in an industrial zone would be more appealing due to the potential in loss of life and infrastructure and economic damage.

Figure 1 Aerial view of Joeffrécourt showing the city center and industrial area locations, and the different sensor positions within the city center

The buildings of Joeffrécourt look like real buildings from the outside, but are empty inside except for some concrete walls and wooden doors. Limited power can be found inside. All floors are accessible as well as each window and some of the buildings also have a roof access (Figure 2).

Figure 2 2 Sensor setup inside a building and on top of roof A

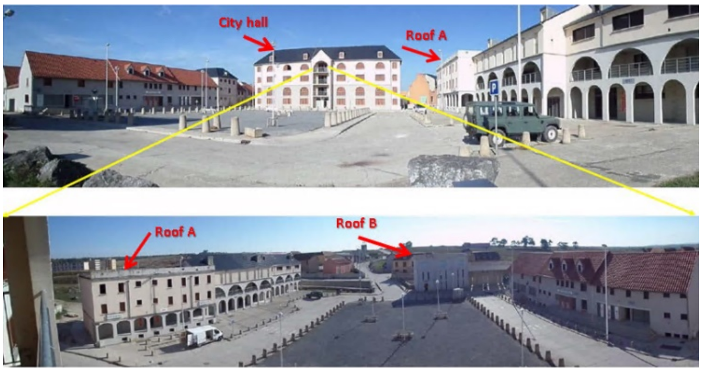

Figure 3 Top: View on City Hall and Roof A from the City Center

Figure 4 Sensor locations in the industrial area

Most of the equipment to collect the background and UAV signatures from participating nations were bulky and required an appreciable time to install. Setup time was scheduled before the trial days in the city center and to move the equipment in the industrial zone, therefore the locations of the installation were chosen to give the different teams a large field of view to collect signature with different backgrounds without having to move the equipment. The main sites where the sensors were located in the city center are shown in Figure 3. In the industrial zone, the systems were deployed in the area shown in Figure 4.

2.2 UAVS

For the trial a number of COTS multicopter and fixed-wing UAVs were used as targets for the sensors. The majority of the flights were conducted using DJI Phantom 2, 3 and 4 quadcopters, both in white and black versions to allow for different contrasts in the visual band. A night trial was conducted using a DJI Mavic2 Enterprise. To cover a broader range of targets, a smaller DJI Spark and Parrot Anafi quadcopters as well as a larger quadcopter (DJI Inspire 2) and hexacopter (modified DJI S900) were also used. A Parrot Disco was the only fixed-wing UAV type used. Finally a DJI Matrice 100 provided a view from the air of the trial.

Figure 5
Top: DJI Phantom 4 black and white
Middle: Parrot Anafi microdrone and Parrot Disco fixed wing UAV
Bottom: Modified DJI S900 hexacopter and DJI Matrice 100 quadcopter

2.3 Sensors

The partners from the 9 nations involved in the SET-260 group brought a wide array of EO/IR sensors to the trial (Table 1), positioned in various locations to acquire a range of fields of view. The bands covered in the trial were the following:

- UV: 200-300nm
- VIS: 400-700nm
- NIR: >700nm
- SWIR: 900-1600nm

- MWIR: 3-5µm
- LWIR: 8-12µm
- Hyperspectral: 400-1700nm

Table 1 Overview of the sensors used in the Joeffrécourt trial

Band	Name	Details	Location	Country
VIS	Allied Vision GT1920	200 mm and 50 mm lenses	Roof A	CAN - DRDC
	Hyperspectral	440 spectral bands 400 nm-1000 nm	Farm	FRA-DGA
	JAI CM 200-MCL	MODISSA vehicle		DEU-IOSB
	Baumer VLG-20C.I	MODISSA vehicle		DEU-IOSB
	Dahua SDZ2030S-N	5.5-135 mm	City Hall	NLD-TNO
SWIR	Goodrich 640HSX	100 mm lens	Roof A	CAN - DRDC
	Hyperspectral	240 spectral bands 900 nm - 1700 nm	Farm	FRA-DGA
	Sony XC-75CE	16 mm	City Hall	NLD-TNO
	Xenics Bobcat 640- GigE	35 mm	City Hall	NLD-TNO
MWIR	MATIS	Variable	Farm	BEL
	FLIR SC7600	50mm	Farm	BEL
	IRC 912	100 mm lens	Roof A	CAN - DRDC
	FLIR SC7600	50 mm	City Hall	NLD-TNO
LWIR	FLIR		Farm	BEL
	Allied Scientific Atom 1024	100 mm lens	Roof A	CAN - DRDC
	Jenoptik IR-TCM 640	MODISSA vehicle		DEU-IOSB
	FLIR SC7750L	50 mm	City Hall	NLD-TNO
Others	RF Agilent spectrum analyzer		Farm	BEL - RMC
	SWIR Gated Camera	Active system	Roof A	FRA-ISL
	RISLING SWIR Gated Camera	Active system	Roof A	FRA-ONERA
	POMEROL SWIR 3D LADAR	Geiger Mode APD FPA	Roof A	FRA-ONERA
	Reflectometer	7 wavebands 335 nm - 2500 nm	Farm	FRA-DGA
	Reflectometer	6 wavebands 900 nm - 12 um	Farm	FRA-DGA
	Mobile LIDARs	MODISSA vehicle		DEU-IOSB
	ProxiCam RL4	UV, 105 mm	City Hall	NLD-TNO
	Acoustic sensors		Roof B	FRA-ISL

Some signature collection systems add multiple sensors boresighted on a platform, allowing the collection of signature with the same UAV position and background features. An example of such sensor system is shown in Figure 6. The sensors were positioned at different location in the urban test site, within the city center (Figure 3) for the first half of the trial, and the industrial zone during the second part.

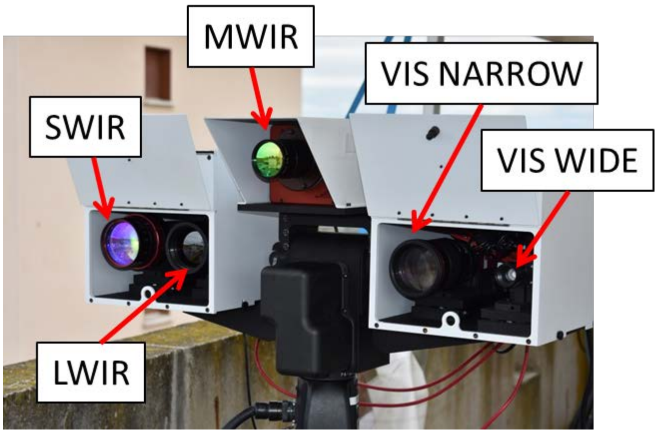

Figure 6 ALEXIS multi-sensor setup from the Canadian team (DRDC)

In addition to this, two active imaging systems operating in the SWIR band were present as well as a mobile lidar mapping vehicle. Static hyperspectral (335-1200nm) signature measurements of each UAV with the urban background were also taken with hand-held reflectometers. A met-station recording the meteorological conditions of the trial was also present. Although it was not a main objective of the trial, some acoustic and RF signature measurements were also performed.

2.4 Flight paths

As the main objective of the trial was to collect UAV signatures with an urban background, UAV flight paths were planned before the trial with the following requirements:

- Sensing ranges between 10 and 200m
- A variety of backgrounds, including sky, sun, buildings, roofs, windows and trees
- Day and night observations
- Single and multiple UAVs in the scene
- Multiple sorties in the same conditions

During the trial, the planned flight plans were adapted on the demand of the sensor operators to take into account the physical constraints of the site and to make sure good signatures were recorded.

The actual executed flight paths were either extracted from the drone's flight controllers, or in the case of the DJI drones, recorded using a drone detection and monitoring unit. The positions of the sensors were measured using GPS, this way we managed to obtain a ground truth for the relative positions of drone and sensors during each recorded sortie.

Examples of flight paths followed in the city center area are shown in Fig 7 (blue, green, red and yellow lines). The sensors were distributed in the locations marked with an X.

Figure 7: UAV flight paths in Joeffrécourt city center

Figure 8 UAV flight paths in the industrial zone

3.0 MEASUREMENT RESULTS

Over the 10 days of the trial, a large amount of data was gathered by the different teams. The group approach to share and analyse the collected signatures is to first identify UAV runs where most sensors has good data and concentrate the efforts on the analysis of the data generated during these good runs.

We will now provide an overview of the measurement setups of the different teams, the technology they used and their experience and initial results. This overview covers passive multisensor EO/IR measurements, active imaging technologies, hyperspectral signature measurements and tracking-based UAV detection algorithms. We will not cover the RF and acoustic detection methods employed at the trial, since these fall outside the scope of this article.

3.1 DRDC: ALEXIS Measurements

For this trial, Canada developed a system to collect UAVs signatures in multiple spectral bands with specifications based on the lesson learned from previous campaigns. The system brought to this trial is called Automated Light EXperimental Imagery Systems (ALEXIS). This system includes five cameras: two visible (narrow and wide FOV), SWIR, MWIR and LWIR cameras mounted on a motorized pan and tilt (FLIR D300 model). The cameras in the system are described in Table 2, and it is shown in Figure 6.

Table 2 Sensor systems included in ALEXIS

Camera	Res	Lens	Band	Wavelength	FPS
Allied Vision GT1920	1936 × 1216	200 mm	VIS	Approx. 400 – 700 nm	8
Allied Vision GT1920	1936 × 1216	50 mm	VIS	Approx. 400 – 700 nm	8
Goodrich 640HSX	640 × 512	100 mm	SWIR	0.7 to 1.7 µm	30
Atom 1024	1024 × 768	z	LWIR	8 – 12 µm	30
IRC 912	1280 × 1024	100 mm	MWIR	3 – 5 µm	18

ALEXIS is controlled by DRDC’s in-house software, called Versatile Tracking System (VTS). This software allows the adjustments of the camera settings, recording and control of the pan and tilt. Manual tracking was done during the campaign since auto tracking was not implemented for the trial. Reference targets were recorded during the test to calibrate images. Two blackbodies were used: one 8 inches SBIR and one 12 inches in-house. A reference plate made of Spectralon was also installed during the test, but not all time due to rain period.

During the campaign, DRDC wat installed on the top of a building for the tests in the City Center and was installed on the ground in the Industrial Zone. Day and night flights were conducted at the City Center area.

A mobile camera, Allied Vision GT1920, was installed in the center place and on a roof top to take other signatures aspects. The camera setup is shown in Figure 5.

Figure 9 Allied Vision GT1920 mobile camera

DRDC collected signatures of all UAVs flown during the campaign in visible, SWIR, MWIR and LWIR spectral bands. These will be analyzed to determine which band offers the best contrast to track the UAV and which offers the highest level of detail to identify it. First observations were not sufficient to determine which one, but previous tests in rural and open field environment demonstrated that EO/IR system to counter UAV must be composed of multi-band sensors. Algorithms of tracking and detection will be tested to determine which offers the best results.

Figure 10
Top: ALEXIS visual measures of DJI Phantom against treeline and building backgrounds
Middle: Images during day tests (VIS and SWIR)
Bottom: Images during night tests (LWIR and VIS)

This training site is not always occupied. Therefor birds are installed in the building and they flew during the flight of the UAVs. No collision occurred during tests between a bird and a UAV. The presence of birds was an opportunity for us to take images of UAVs and of birds (confusers) at the same time. These images are a good means to test classification algorithms to separate the false alarm (birds) from the true one (UAV). Sequence with two drones done during the tests will be helpful to test tracking algorithms. Similar drones were flown at the same time, and we will test the robustness of the algorithms.

It was planned to fly the UAV at 3 speeds (3, 5, 8 m/s) and to follow waypoints. After the first morning of tests, it was decided to keep only low-speed flight and use manual flight. This decision was helpful for us since it was difficult to track the UAV at high speed.

Night tests were interested to perform to evaluate which sensor offers the best performance. As expected, the IR sensors gave the best results. Even if it was dark, the horizon was bright enough to allow the recording of some images with the visible camera. However, we conclude that the IR camera must be present in a system to counter UAV to encompass these conditions.

Datasets collected will be integrated in the current database to add diversity and stressors for the AI algorithm development. These algorithms will be used to detect, but they will be used specially to classify and identify the threat. This work is conducted to reduce the workload of the operator.

3.2 RMA EO/IR measurements

Figure 11 RMA sensor setup at the UAV base, from left to right MATIS (MWIR), FLIR SC640 (LWIR), FLIR SC7600(MWIR)

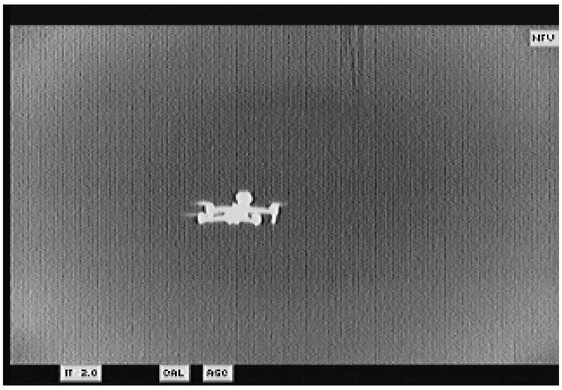

Figure 12 Footage of a DJI Mavic 2 Enterprise captured by a MATIS MWIR camera during the night

RMA used two MWIR and one LWIR cameras during the trial. These were set up at the “farm” building in CENZUB facing the town center and the industrial zone. This allowed us to record longer range data against an urban or industrial background, with the UAV periodically entering and leaving occlusion zones. Also used was acoustic recording equipment which was used in a directional multi-microphone setup, or as a handheld microphone recording drone audio around the site.

The cameras used were a MATIS MWIR camera recorded through an analog interface, and FLIR MWIR and LWIR cameras recorded via Ethernet and firewire interfaces. The MATIS, being a military system for air defense, performed really well at longer distances despite its limited datalink and low resolution.

3.3 ISL Range gated active imaging

Electro-optical sensors such as CCD cameras are commonly used to record intensity images which are processed by automatic tracking algorithms or by a human operator in order to localize a flying object.

Due to a very narrow field of view (FOV), optical sensors have to be precisely oriented in the direction of the object under investigation and, thus, rely on external sensor information given, for example, by acoustic and/or radar systems.

In most cases, the tracking of a flying object with the sky as a background can be made without any problem: the contrast of such images is always very high and the system is able to track the target.

Figure 13 ISL Range gated active imaging setup on top of Roof A in the City Center

However, when the drone is flying in front of a structured background such as trees or buildings, it can become very complicated to distinguish the object. A vision system able to give an image of the threat without its background could be of great help for tracking. This is precisely what a range-gated active imaging system can do: if the gate is thin enough and placed at the right distance, this technique is able to suppress the foreground and the background around the object. Figures 13 and 14 shows an example of such a system and its vision capacity.

The sensor consists of a color camera associated with a range-gated active imaging system. The latter consists of a solid-state laser emitting light in the eye-safe short-wave infrared (SWIR) spectral range coupled with a SWIR camera. The laser is collimated and homogenized by an ISL patented waveguide technology in order to enable illumination with a homogeneous top-hat profile which fits to the sensor field of view. The imaging sensor is an EBCMOS array from INTEVAC (LIVAR M506) with a resolution of 640 × 512 pixels. To ensure a good resolution on the flying target, a 100 mm or 200 mm OPTEC SWIR lens is used. This lens provides an active imaging FOV of ~3.15° or 6.3° respectively. The system is placed on a pan and tilt device capable of rapidly moving in the direction of the detected threat.

The use of short laser pulses and short exposure times on the sensor unit makes it possible to perform the range-gated imaging of the scene. Only the light which arrives at the sensor within a certain timing window contributes to the imaging process. In Figure 14 the wide-angle color image of the UAV and the narrow-FOV laser gated image of the same object can be observed. While the UAV is more or less invisible in front of the structured urban background, the contrast gain on the UAV with the active imaging system is clearly visible.

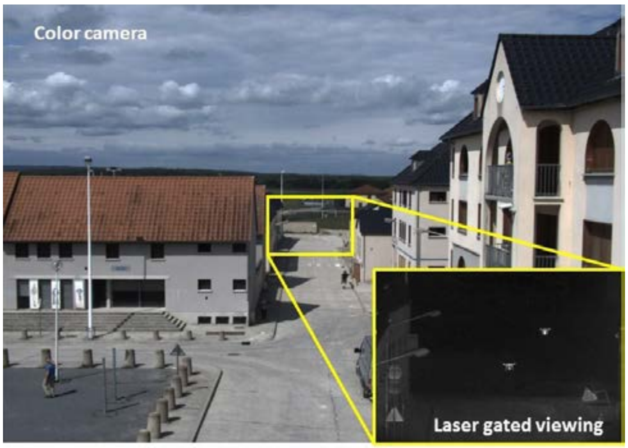

Figure 14 Visual image and SWIR laser gated image of DJI Phantom

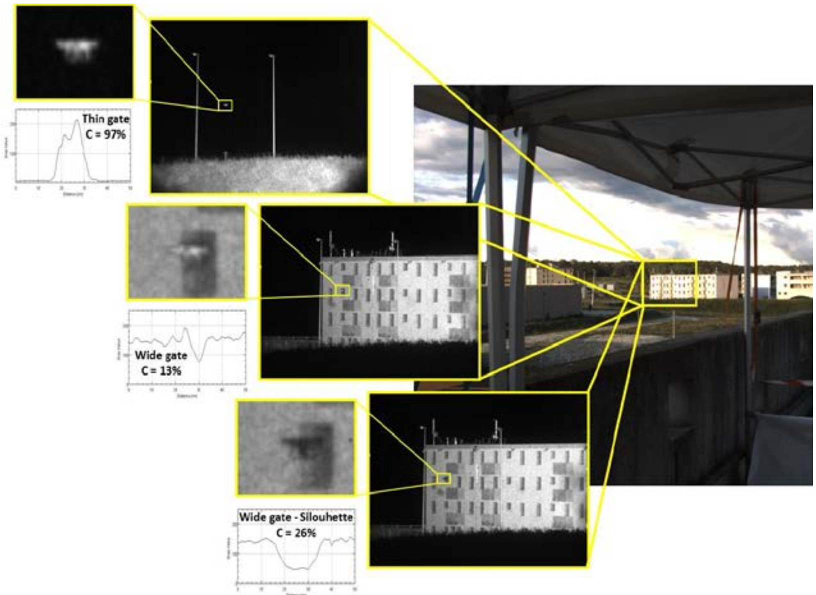

Figure 15 From right to left : wide FOV color image, range-gated images at a distance of 240m with different gate positioning, thumbnail of the UAV in the gated images and contrast measurements of the UAV for the different cases

With a 50 mJ illumination power and a very sensitive SWIR camera (energy threshold for a difference of 1 LSB on a pixel, Eth < 0.65 W/m2 for a 10 ns exposure time on the Intevac EBCMOS), the system is able to produce a luminous image of a drone situated at more than 2 km of distance even if the reflectivity of the material is not very high (e.g. carbon fiber).

The benefit of range-gated active imaging in comparison with the color image is clearly visible in Figure 15. By using a thin gate and rejecting the background and the foreground the contrast on the tracked UAV is of 97%, instead of 13% by using a wide gate. The technique of silhouetting can also be used to enhance the contrast by a negative effect, but in this case it is less efficient than without background.

ISL has published their work on detection and tracking of UAVs using active and passive sensors, and using deep learning based tracking in a number of conferences [1-4].

3.4 ONERA-EXAVISION Active laser EO imager

With the support of an internal program of ONERA research on CUAS (PDEV SHIELD), ONERA and its partner EXAVISION have participated to the NATO SET 260 « Assessment of EO/IR Technologies for Detection of Small UAVs in an Urban Environment » trials which took place on the CENZUB from June 8 to 14, 2019.

For these trials, ONERA has implemented three various EO laser imagers, namely:

- RISLING1: a 2D flash gated laser imaging camera based on APD-MCT FPA and an OPO laser working at 1.57µm (up to 70mJ per pulse). This camera was tuned for long range application as it fixed IFOV is narrow (11µrad) and a limited FOV 0.27° x 0.2°. Its TRL is around 3-4.
- POMEROL: a 3D LADAR camera based on Geiger Mode APD FPA having photon counting capacities and a high PRF laser working at 1.55µm (150 µJ per pulse). The IFOV is 100 µrad and the FOV is 0.6° x 0.6°. Its TRL is around 3-4.
- A COTS 3D laser scanner VZ 1000 from Riegl.

Figure 16 ONERA-EXAVISION setup in the City Hall and on top of Roof A in the Joeffrécourt City Center

These tests were carried out jointly with two passive EO cameras (NEMOSYS-LR – TRL 92) coupled with “on development” tracking scheme (VIGISENS TRACKING – TRL 6) and a 2D laser imaging camera prototype (NEMOSWIR – TRL 6), all provided and implemented by EXAVISION. The main characteristics of the cameras EO are a continuous variable focal length (36-860mm focal length zoom lens coupled with a 15µm pitch 20mK NETD, MWIR cooled camera for infrared vision and a continuous variable focal length (16-1030mm) coupled with a Full HD 1/3 “ CMOS sensor for visible spectrum. The 2D laser flash camera NENOSWIR is devoted for short/medium applications and it is based on an InGaAs FPA with a logarithmic ROIC, an OPO laser (up to 35mJ per pulse) with 3 selectable divergences set, an objective with continuous variable focal length (f = 20 to 750mm). At maximum resolution, the IFOV is 20 µrad and the FOV is 0.73° x 0.55°.

During two day on the industrial zone, short range radar was also deployed to test tracking algorithms. During the “city center” location, ONERA and EXAVISION was placed on the roof of the building and on the 3rd floor of the city hall. For the industrial zone location, all the instruments were settled on the same place.

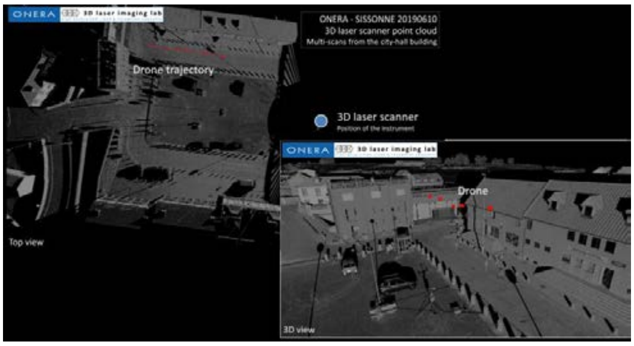

Figure 17 UAV detection and tracking by 3D scanning

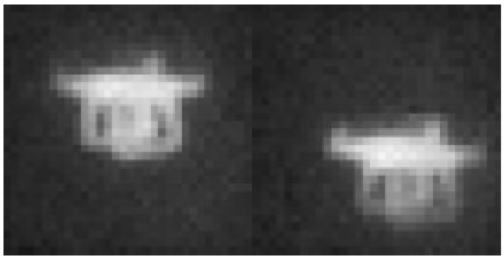

Figure 18 DJI Phantom observed by 3D photon counting at 150m

For the 3D lidar systems, we have obtained good detection and tracking considering the quite small field of Regards we decided to survey (30°). An illustration of a typical result here at short range is presented here on the following figure. Longer range for detection and tracking were obtained but the results are not yet exploited. Work is also on progress to suppress false alarms (Birds…).

For the 3D laser camera systems, the 3D shape of the drone are not yet processed but on photon counting observation, the 2D shape of the drone could be observed at low range.

Figure 19 Left to right: RISLING image of DJI Phantom at 980m, NEMOSWIR image at 200m, NEMOSWIR at 650m

For the 2D laser camera systems, the 2D shape of the drone is retrieved at long range by RISLING system (> 900m) but at lower range, the image are blurred due to focus of the camera not adaptable at such distance. TheNEMOSYS 2D laser camera produced accurate results during day trial until 350 m and becomes noisy above 600m. During night trials, the range was limited to 350m.

During the trials, very accurate outcome was given by the IR or EO tracking developed by EXAVISION as long as the drone was observed on sky background. On urban background, the clutter makes the tracking less effective.

Figure 20 Left IR tracking with NEMOSYS-LR, Right: Illustration of fixed wing detection using EO/IR NEMOSYS camera at 200-300m

3.5 Fraunhofer-IOSB MODISSA

In the near future, military vehicles will be equipped with a variety of sensors, computers and communication systems, e.g. to enhance situational awareness in these vehicles. Similar developments can be observed in the civil market, where the development of sensor-based driver assistance functions is driven by a growing interest in safety and comfort. However, military boundary conditions lead to different requirements for the sensor equipment, e.g., of combat vehicles. The use of the selected sensors should enable the following capabilities:

- Target detection, target location, target tracking, target designation and target handoff between vehicles.
- Self-protection of the vehicle by real-time detection and analysis of threats.
- Area-wide acquisition of georeferenced sensor data to provide an up-to-date database to be shared among coalition partners.

Our main focus in the context of the NATO SET-260 “Assessment of EO/IR Technologies for Detection of Small UAVs in an Urban Environment” is the investigation of mobile LiDAR systems (MLS) for UAV detection in close-range, e.g., to evaluate the capabilities of available commercial MLS sensors for the protection of military vehicles against UAV attacks. In addition, such MLS sensors are used for the 3D mapping of the operational area, to provide context information for further analysis.

“MODISSA” is Fraunhofer IOSB’s realization of an experimental platform for hardware evaluation and software development in the above contexts (sensor equipment of future military combat vehicles).

It is based on a Volkswagen van VW T5 that has been equipped with a broad range of sensors and contains hardware for complete raw data capture, real-time data analysis, and immediate data visualization on in-car displays. The VW van carries several sensors on a roof rack, and a power supply as well as operational electronics inside.

The sensor configuration can be adapted to the needs of the respective study. The electronics, including several PCs, are located in a rack behind the driver's seat. The power for the sensor system is provided by four high-capacity Li-ion batteries that are stored in a box in the back of the van. This power system has sufficient capacity for several hours of independent operation.

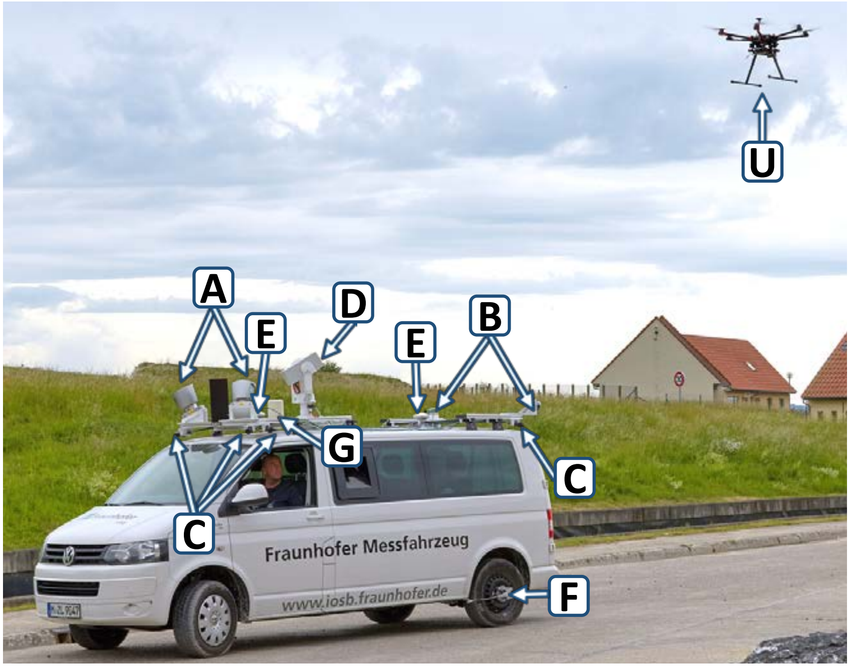

Figure 21

A: 2x Velodyne HDL-64E LiDAR
B: 2x Velodyne VLP-16 LiDAR
C: 8x Baumer VLG-20C.I (panoramic camera setup)
D: Jenoptik IR-TCM 640 LWIR camera, JAI CM 200-MCL gray scale camera, and Jenoptik DLEM 20 laser rangefinder (on pan-tilt unit)
E and F: Applanix POS LV V5 520 inertial navigation system (IMU, GNSS receiver, DMI)
G: External WiFi antenna
U: DJI S900

MODISSA is equipped with several scanning LiDAR sensors, several cameras for omnidirectional monitoring, an EO- and a SWIR camera on a pan-tilt head and an inertial measurement unit (IMU) and two GNSS receivers (Figure 21). The LiDAR sensors are two Velodyne HDL-64E mounted on the roof in the front of the vehicle combined with two LiDAR sensors Velodyne VLP-16 mounted on the roof in the back of the car. Each HDL-64E is capable of performing 1.3 million measurements per second in a range up to 120 meters. Its vertical FOV is 26.9° is divided into 64 scanlines resulting in a vertical resolution of 0.4°. Due to the rotating sensor head, the horizontal field of view covers 360° with a resolution of about 0.17° at a typical rotation frequency of 10 Hz. This means that every 360° scan could consist of approximately 130.000 measurements. The smaller VLP-16 has a vertical FOV of 30° generated by 16 scanlines, leading to a vertical resolution of 2°. At a rotation frequency of 10 Hz, the horizontal resolution is about 0.2° and a single 360° scan could consist of up to 30. 000 measurements (3D points).

The UAV detection method currently implemented on MODISSA uses the 360° scans of all four scanning LiDAR sensors to monitor the vehicle's environment. If a potential threat (flying object) is detected, the pan-tilt head is pointed in that direction to verify and identify the UAV. Figure 22 shows a screenshot of MODISSA’s onboard display, showing the 3D LiDAR data and the real-time detection of a UAV in the vicinity of the car. This approach was published [5] and was extensively tested during the CENZUB measurement campaign. MODISSA’s recorded sensor raw data (approx. 3 TB) will provide a solid basis for further algorithm development and improvements.

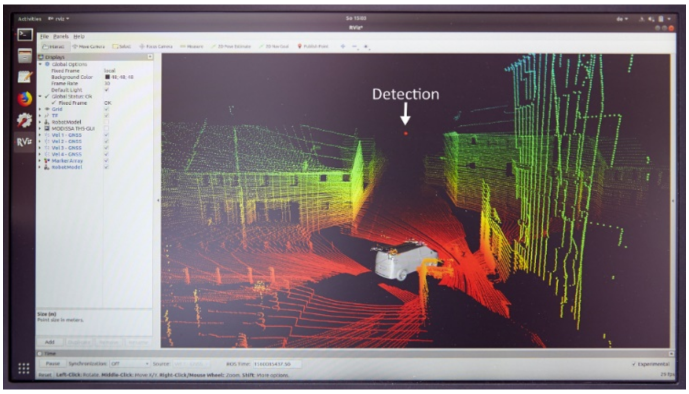

Figure 22 MODISSA real-time detection of UAV using 3D LiDAR in the Joeffrécourt City Center

3.6 DGA Hyperspectral signature measurement

Two hyperspectral cameras and two reflectometers were used during this trial. The first camera is a hyperspectral one working in the visible and Near IR wavebands covering the wavelengths from 400 nm to 1000 nm. This camera acquires 440 spectral wavelengths (with a 1.4 nm average spectral resolution) on a 1600 pixels resolution line. The second one is a hyperspectral camera with a SWIR sensor (InGAs) covering the wavelengths from 900 nm to 1700 nm. This camera acquires 240 spectral wavelengths (5 nm average spectral resolution) on a 320 pixels resolution line. The cameras were set on scanning systems for getting hypercube images on the whole scene of interest.

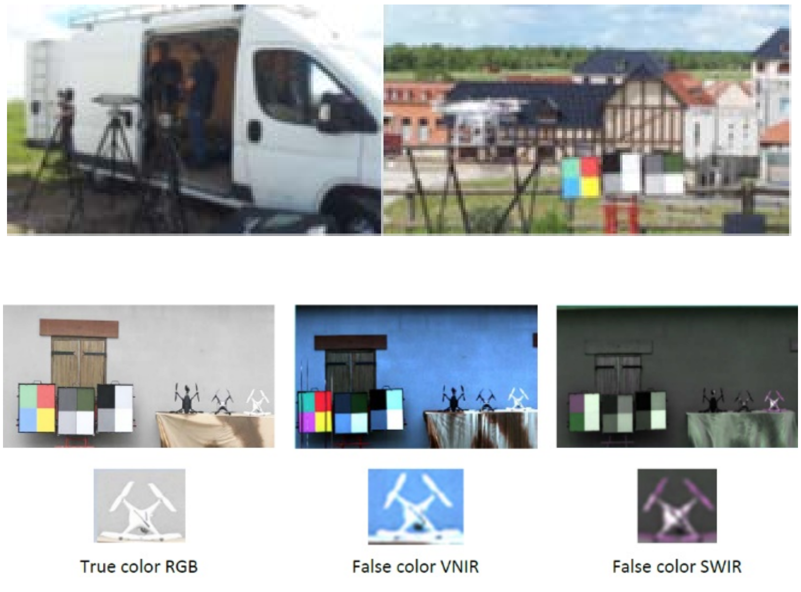

Figure 23 Spectral measurement setup and measurements in true RGB, VNIR and SWIR

Calibration reflectance panels (Spectralon) are used in the field of view in order to calibrate the spectral images. The man-held reflectometers are here to measure the emissivity and the reflectivity of UAVs and background materials. The first one measures 7 wavebands from UV (335 nm) to SWIR (2.5 µm), the second one measures 6 wavebands from Near IR (900 nm) to LWIR (12 µm).

Two panoramic hyperspectral images of backgrounds are measured: city center and industrial area. The two cameras are set on the ground to be stable . Calibration reflectance panels are visible within the scene.

In order to characterize the UAVs spectral signatures, UAVs were set in front of a wall with calibration reflectance panels within the camera field of regard.The materials radiometric characteristics were measured on small areas on the UAVs and backgrounds.

First, the hypercubes are calibrated with the reflectance panels to obtain the apparent spectral reflectance of the UAV and background. The results are:

- spectral reflectance of UAVs and backgrounds from 400 nm to 1700 nm (Figure 24);
- false color pictures with 3 wavelength images used as RGB set (Figure 23);
- materials emissivity and reflectivity table.

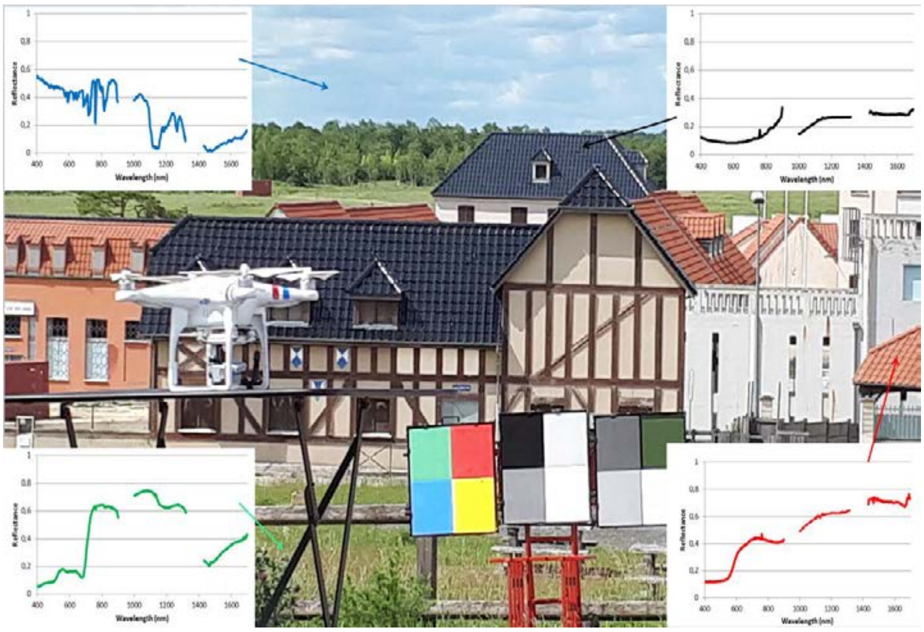

Figure 24 Reflectance profile measurements

3.7 TNO EO/IR measurements

The EO/IR setup of TNO consisted out of six cameras spanning from the UV all the way into the LWIR part of the spectrum. Table 1 contains the main characteristics of these cameras. The left image in Figure 1 shows the EO/IR setup mounted on top of an Instro Mantis high accuracy motorized pan and tilt unit. This high-torque (100 Nm) unit is capable of pan/tilt movements ranging from 0.0056 °/sec all the way up to 50°/sec with a position accuracy of 0.056°.

Both the MWIR and LWIR cameras were radiometrically calibrated. For this purpose, two DCN1000N12 black body reference sources from HGH Infrared Systems were used in the field. The black body sources were also used to perform non-uniformity corrections on the IR systems. The sources can be seen to the right of the EO/IR setup in the same picture.

Table 3 Sensors in the TNO EO/IR setup

Brand	Type	Band	Wavelength	Res
Proxitronic	ProxiCam RL4	UV	200 – 305 nm	756 x 581
Dahua	SDZ2030S-N	VIS	Approx. 400 – 700 nm	1920 x 1080
Sony	XC-75CE	NIR	> 700 nm	752 x 582
Xenics	Bobcat 640-GigE	SWIR	950 – 1650 nm	640 x 512
FLIR	SC7600	MWIR	3.5 – 5.5 µm	640 x 512
FLIR	SC7750L	LWIR	8.0 – 9.4 µm	640 x 512

Data acquisition was performed from a trials van containing four industrial grade computers, capturing data directly onto individual RAID-0 (mirroring) setups allowing for instantaneous data backup. The right image in Figure 25 shows this computer setup.

The TNO EO/IR setup was positioned at two different locations during the trial. During the first three days, the setup was placed in the city center on the 3rd story of the Town Hall.

During the last two days, the setup was placed on a hill at the edge of the town that also acted as the UAV Base. From here, parts of the city center, historical center, north residential area, south residential area, industrial zone and modern zone are all visible.

TNO's EO/IR measurement setup was used during the trial to capture imagery in six wavelength bands from an array of different UAVs. The UAVs were captured against both a sky background and an urban environment background. Figure 26 shows some example imagery of a UAV against a sky background. The acquired data allows for future analysis of different detection methodologies in different wavelength bands and/or combinations thereof.

Figure 25 TNO EO/IR setup and trials van interior

The recordings of the cameras have been processed in order to detect and track any present drones. The processing follows the sequence of steps as showed in Figure 27. After removing any lens distortion effects in the images, the frame-to-frame pixel displacement due to pant-tilt camera motion is estimated; this allows the registration of frames over time.

The detection of drones is based on moving object detection: frame differences over time constitute candidate detections. A subsequent tracking step will associate detections over time, producing series of consistent spatio-temporal detections. Furthermore, it enables the filtering of tracks based on certain characteristics like duration and spatial displacement. In this final filtering step, many false alarms can therefore be discarded. In the following, detection of a drone will refer to the drone being in track after the filtering stage.

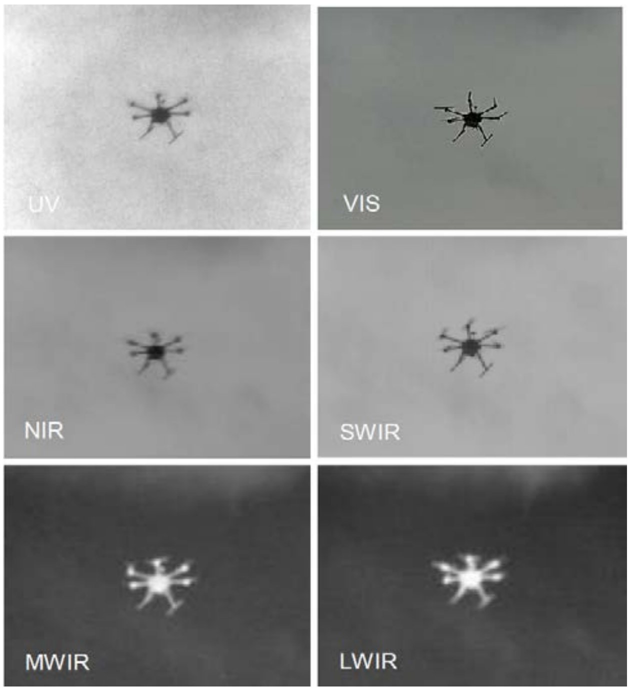

Figure 26
Images of DJI S900 against a sky background in UV, VIS, NIR, SWIR, MWIR and LWIR

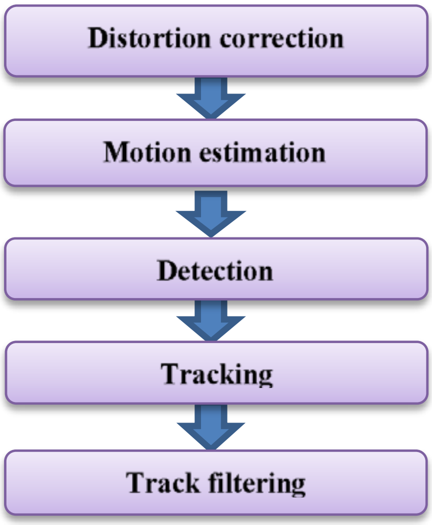

Figure 27 TNO UAV detection algorithm

In total six wavelength bands have been used for making recordings, namely LWIR, MWIR, SWIR, NIR, VIS and UV. The LWIR, MWIR and SWIR imagery have been processed using the sequence of steps above. Since the VIS sensor has been used for zooming in on the drone while recording, it is not used in the comparison. However, it was noted that the visibility of the drone is good in the visual recordings, as is the expected automatic detection rate. Compression artefacts had a negative influence on the image quality, though. The low quality of the UV imagery made it not suitable for achieving high detection rates, and the same holds for the interlaced NIR imagery which has low spatial resolution during camera motion.

4.0 CONCLUSIONS

The NATO SET-260 Research Task Group is aiming at collecting UAV signature in the EO/IR band against an urban type background in order to evaluate potentially better spectral band for detection/tracking UAV systems. A joint trial was organised at the simulated village of Joeffrécourt in the French Armed Forces urban training facility, CENZUB in June 2019. Nine nations participated and collected UAV/urban background signature in different spectral band covering UV to LWIR.

We presented the data gathered by the teams, covering passive multi-sensor EO/IR setups, various active imaging and 3D scanning systems and hyperspectral foreground and background signature measurements, and the initial findings regarding the detection performance of these systems on multiple types of UAVs, whether used by an operator or exploited by a detection algorithm.

From the initial reporting it is clear to us that active imaging systems, both gated imaging and LiDAR systems, have a tremendous 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 which 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.

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