Reconnaissance of LSS-UAS with Focus on EO-Sensors

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ABSTRACT

Low, Slow and Small Unmanned Aerial Systems (LSS-UAS) are powerful, cheap, and can be purchased and operated by everyone. Modifications and add-ons for different operational tasks can easily be configured. LSS-UAS with surveillance sensors or explosive ordnance as payload create new challenges for today's war fighters.

Relevant sensors for the detection of LSS-UAS are Radars, EO-surveillance sensors (IRST- Infra Red Search & Track) and Passive Emitter Localization sensors (PEL). Methods based on single sensors do not perform satisfactory and intelligent sensor data fusion is necessary in order to improve detection. The threat classification and identification may be done by EO sensors and can be assisted by Radar, ESM and Acoustics.

Current GBAD systems are not designed for LSS-UAS threats. Military applications in different scenarios such as "Stationary Asset Defence (SAD)" and Mobile Force Protection (MFP)" need specific adaption of system configurations and sensor design.

This paper and the presentation concentrates on detection and verification of LSS-UAS threats with EO sensors (IRST, cooled and uncooled IR thermal imagers, day sight cameras) in conjunction with powerful image processing functions (detect, track, classify, identify). EO- sensor configurations for stationary asset defence and mobile force protection are being described and the results of performed trials explained.

Further on, exemplary operational scenarios, improvement of algorithms by combination of different sensors, results from relevant NIAG studies, C-UAS trials and relevant German R&T studies will be presented. Also the description of standardization activities for sensors, interfaces and plug-in functionality (based on NGVA = NATO Generic Vehicle Architecture) as a military demand for mission component interchangeability and lower serial production costs is content of the paper.

1.0 LSS-UAS threats

Low, Slow and Small- Unmanned Aerial Systems (LSS-UASs) are commercial available and can be operated easily by everyone. These LSS-UAS are typically equipped with sensors and electronics to assist the remote operator for easy control of the LSS-UAS flight path and delivery of First Person View (FPV) Video. Beside leisure activities these LSS-UAS can also be used for spying, terrorism and military purposes. LSS-UAS are used for reconnaissance and strike of targets without putting pilots live at risk.

LSS-UASs use advanced technological equipment and the research on these devices is providing continuous improvements by increasing performance, high autonomy, long range operation, acceptable accuracy and extreme versatility which makes them suitable for many purposes.

Threats from terrorist UASs first became an issue of concern for the U.S. Government after September 11, 2001. UASs changed the way of military thinking and act in different conflict situations, making it possible to gather unprecedented amounts of aerial imagery and other intelligence information on targets of interest. Also they can carry a significant payload to attack and harm mobile and stationary assets.

Several UASs can be combined in a networked swarm, which increases UAS threat potential. Technologies for synchronised actions of an UAS swarm are already available. Counter measures against UAS swarms have to deal with a reduced reaction time for the single UAS and sufficient "ammunition" available for a swarm.

1.1 LSS-UAS in military operational scenarios

LSS-UAS are a threat for stationary and mobile troops and assets. For counter- UAS proposes the following operational tasks and scenarios can be defined in the military and asymmetric area (see figure 1):

- Stationary, i.e.:
    - Air field protection, camp protection, harbour protection
- Mobile, i.e.:
    - Vehicle protection, convoy protection, troop protection

Figure 1: Stationary and mobile C-UAS scenarios

1.2 LSS-UAS threat characteristics

Small and mini drones may have the greatest potential to impact national security and privacy, because they can be easily acquired, transported anytime and anywhere and can be almost undetectable when they fly due to having a very low signature. Small and mini drones are already a military operational reality but micro-drones are also increasingly being used with their unique features.

There are advantages that make drones particularly attractive to malicious groups and/or persons which include (see also figure 2):

- Possibility to attack targets that are difficult to reach;
- Possibility of carrying out a wide-scale (area) attack, particularly through the use of CBRN agents or weapons in populated areas;
- Simple attack preparation, needs no special launching site;
- Poor detection of existing radars and air defence systems against low-flying UAS;
- High performance reconnaissance payloads available (HD-, UHD-cameras, IR, other)
- Possibility of achieving a strong psychological effect.
- Could be smuggled into secure locations and used to carry-out sensitive material

The UAS classes are further broken down into sub-classes as follows:

- **Fixed wing**
- **Rotary wing**
- Rockets
- Hybrids

Categories	Weight [kg]	Type	Payload [kg]	Coverage [km]	Speed [km/h]	Endurance [h]	Altitude [m]
Nano	< 0.5	FW, RW	< 0.1	< 1.5	0..80	< 0.5	< 100
Micro	< 2	FW, RW	< 1	< 10	0..100	< 1.5	< 1500
Mini Light	< 10	FW, RW	< 5	< 25	0..150	< 3	< 3000
Mini Heavy	< 25	FW, RW	< 12	< 50	0..180	< 5	< 4000
Small	< 150	FW, RW	< 50	< 150	0..300	< 12	< 6000

Figure 2: LSS-UAS threat characteristics [1][6]

1.3 Counter-UAS Sensors & Effectors

Main challenge for counter- UAS systems is the timely 360° hemispheric detection of these small UAS. GBAD (Ground Based Air Defence) Radars today are not designed for small and often slow flying UAS. New Radars, or improvements of antenna, electronics, algorithms and signal processing are necessary for detection and tracking, with low FAR (False Alarm Rate), of LSS-UAS. Nevertheless Radars (active or passive) are necessary for all weather operation.

Alternatively, or in addition EO- (Electro- optical) sensors, especially IRST- (360° Infra-Red Search and Track) sensors can be used for 360° UAS detection. ESM (Electronic Support Measures) sensors, especially combined in a network can detect and locate the UAS communication transmitter (First Person View Video signal to the operator), or the operator control station. For stationary applications also networked acoustic sensors are possible. See sensor and effector overview in figure 3.

After detection of a possible UAS object an EO- sighting system, for example, can be assigned to the UAS position and can track the object and measure the range (3D- Tracking). Classification, Identification and Engagement are under human control and will be assisted by signal- and video- processing algorithms.

According to the operational task and scenario lethal, or non- lethal effectors can be engaged to the threat. After impact to the threat an assessment will be necessary to verify the desired effect.

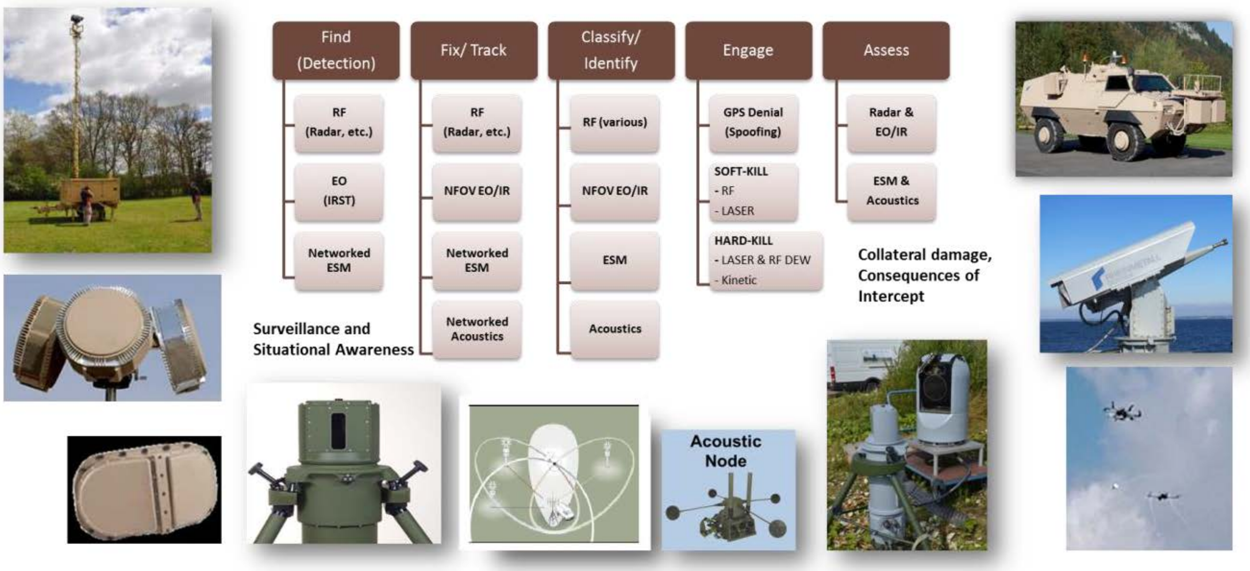


Figure 3: C-UAS Sensor & Effector Options for Engagement Cycle

Most Counter-UAS systems under development are focused on today's threat, which relies on radio frequency (RF)-based remote control or global position system (GPS)-based navigation. However, the next evolution of LSS-UASs will not require GPS or active communications to accomplish their missions. These UAS will be capable of navigating by visual means or other methods, performing synchronized actions that allow large groups to coordinate an attack against one or more moving targets and be used as intelligence assets or as weapons carrying platforms. An effective counter-UAS system must be able to defend against today's and tomorrow's threats and adapt to evolving LSS-UAS technologies and tactics.

1.4 EO/IR- Sensors for counter-UAS application

EO-Sensors are applicable from "Find to Identify". The combination of an EO IRST sensor with a verification sensor in an EO-Sensor Suite allows the detection and verification of threats (see figure 4).
The currently available FIRST sensor can potentially detect LSS-UAS at short ranges (up to 800m). It can be used for real-time surveillance in a stationary environment and on vehicles. For increased detection range additional sensors, like passive/active Radar and ESM, are necessary.

Possible threats detected by an IRST sensor, or other panoramic sensors will be assigned to a co-located verification sensor, which will track the threat with a NFoV TI-, or TV- Sensor for identification and will measure the distance with the integrated laser range finder. The NFoV gives a sufficient resolution for manual or semi-automatic identification. Two or more EO Sensor Suites can be integrated in a network to increase the surveillance area. For overlapping areas a sensor fusion is necessary to eliminate repeated (double) measurements and to increase performance.

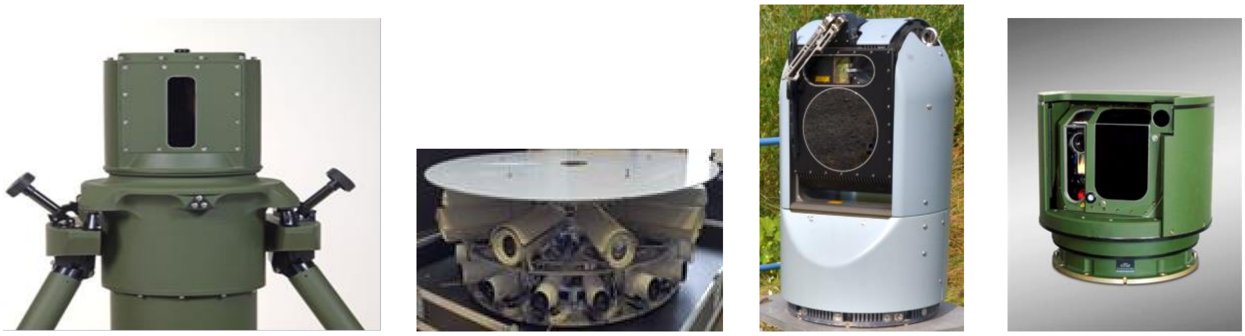


Figure 4: EO-C-UAS Sensor: 360° detection (FIRST, Static IRST), identification (MSP, SEOSS)

1.4.1 EO-IR 360° object detection (IRST) sensor

When a hostile LSS-UAS approaches, the flight path and incoming direction is unknown, therefore a 360° or wide sector reconnaissance is needed to cover the appropriate threat area.

The Fast Infra-Red Search and Track (FIRST) Sensor is preferred for passive IR 360° surveillance in day and night operation (see figures 5 & 6). Also circular combined TI cameras (cooled & uncooled) can be an alternative for passive horizon surveillance (static IRST). With the progress in FPA technology the performance/cost ratio will increase.

The rotating line detector from FIRST delivers 5 times/second a panoramic video image to the image processing and tracking electronics. Detected hotspots in successive videos will be checked if they can belong to the same object. When this is assumed several times (>3 frames) the object will be marked and tracked continuously. If appropriate, an alarm can be generated to the system or operator for additional actions. For example, the measured direction of the alarmed object can be used for the assignment of an EO verification platform (NFoV, LRF) for threat identification.

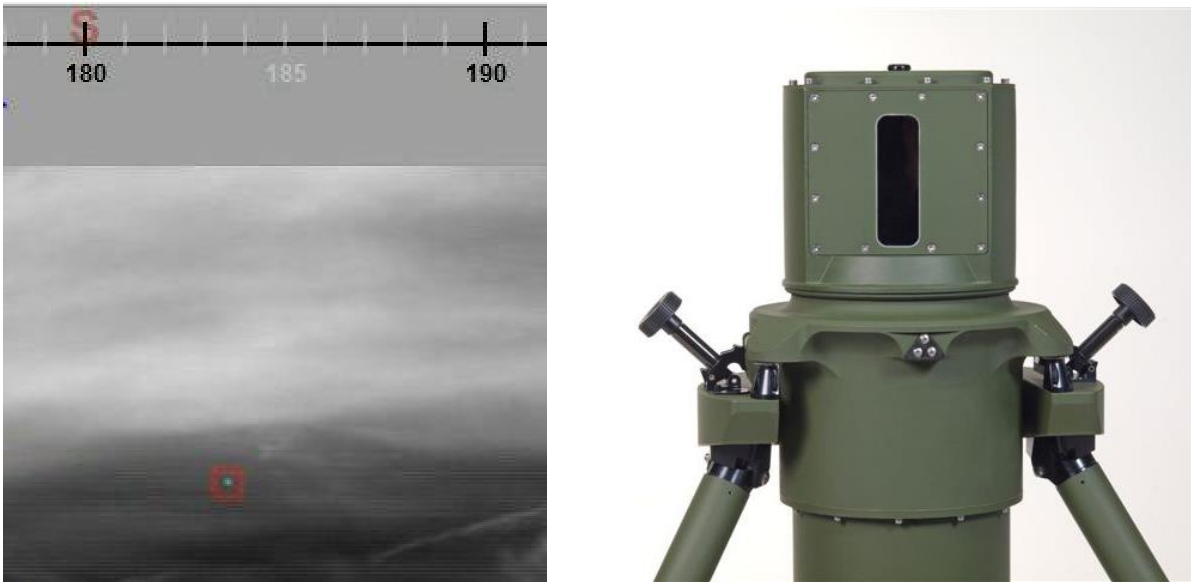


Figure 5: FIRST "hot spot" detection of an LSS-UAS (circled in red)

FIRST Detector	Cooled Line detector
Spectral Sensitivity	7,5µm to 10,3µm
Video repetition rate	5Hz
Azimuth- coverage	360°
Elevation- coverage	18°
Adjustment range elevation	36°
Resolution Azimuth	7200 Pixel / 360° (0,9mrad / Pixel)
Resolution Elevation	576 Pixel / 18° (0,55mrad / Pixel)

Figure 6: FIRST Characteristics

1.4.2 FIRST sensor range detection estimation:

FIRST covers 360° azimuth, refresh rate: 5 times / sec

- IFoV(azimuth) = 2π/7200Pixel = 0,87mrad = 1 Pixel
- Object detection feasible when projected d ≤ 1 Pixel or ≤ IFoV
- Detection range will increase if UAS heat radiation is higher as expected
- Condition: average weather (TRM 3/4) , low clutter
- Hotspot detection feasible, if > S/N >5 (typical w/o clutter disturbances)

⇒ ***Figure 7 shows calculated detection ranges for Mikro & Mini UAS***

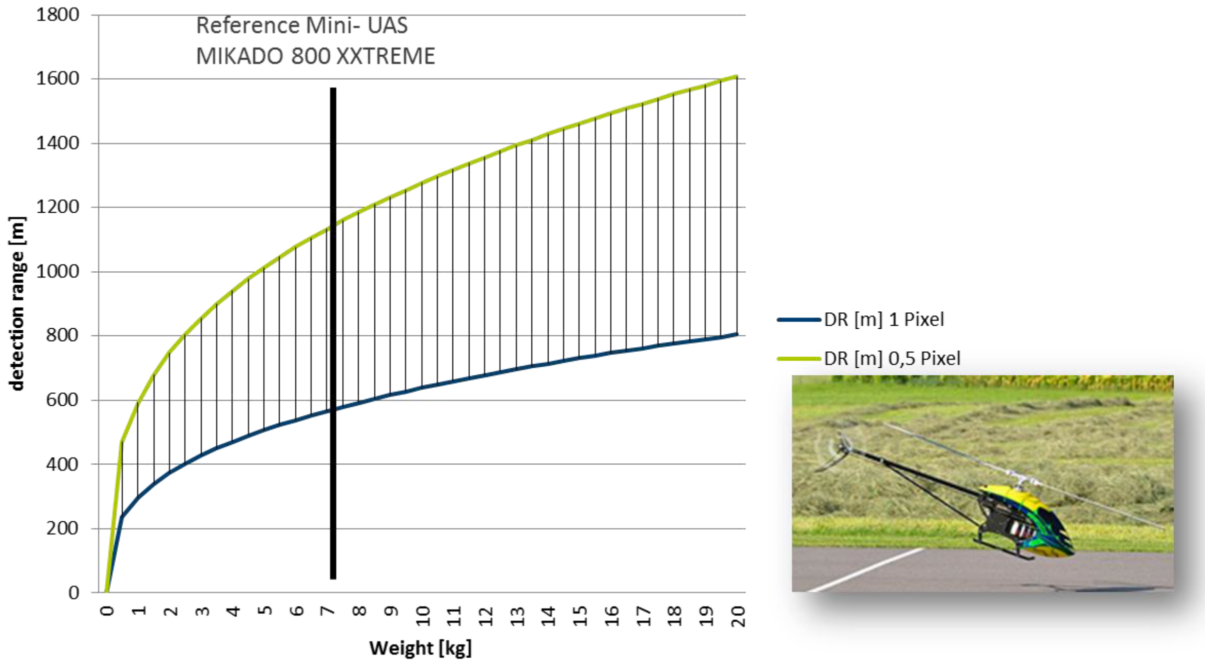


Figure 7: FIRST Sensor detection range, i.e. Mini- UAS

Beside a rotating IRST also a static configuration of EO/IR cameras (static IRST) can be used for detection of LSS-UAS. Therefore, a camera ring is necessary which delivers a sufficient Pixel number for the 360° surveillance. CCD-Camera- or uncooled TI- camera ring solutions are already available.

To achieve the required performance in night and adverse weather application cooled IR thermal imagers are still necessary. With next step in technology also uncooled solutions may reach a sufficient performance with decreased costs.

There is additional effort necessary to achieve a good static IRST performance, such as:

- Image processing for video stitching of the several cameras (geometric distortion, intensity alignment, etc.)
- As well as for 360° azimuth coverage, the elevation coverage also needs additional cameras
- The increased numbers of cameras require increased bandwidth to handle the video data rate and the associated automatic target recognition processing.

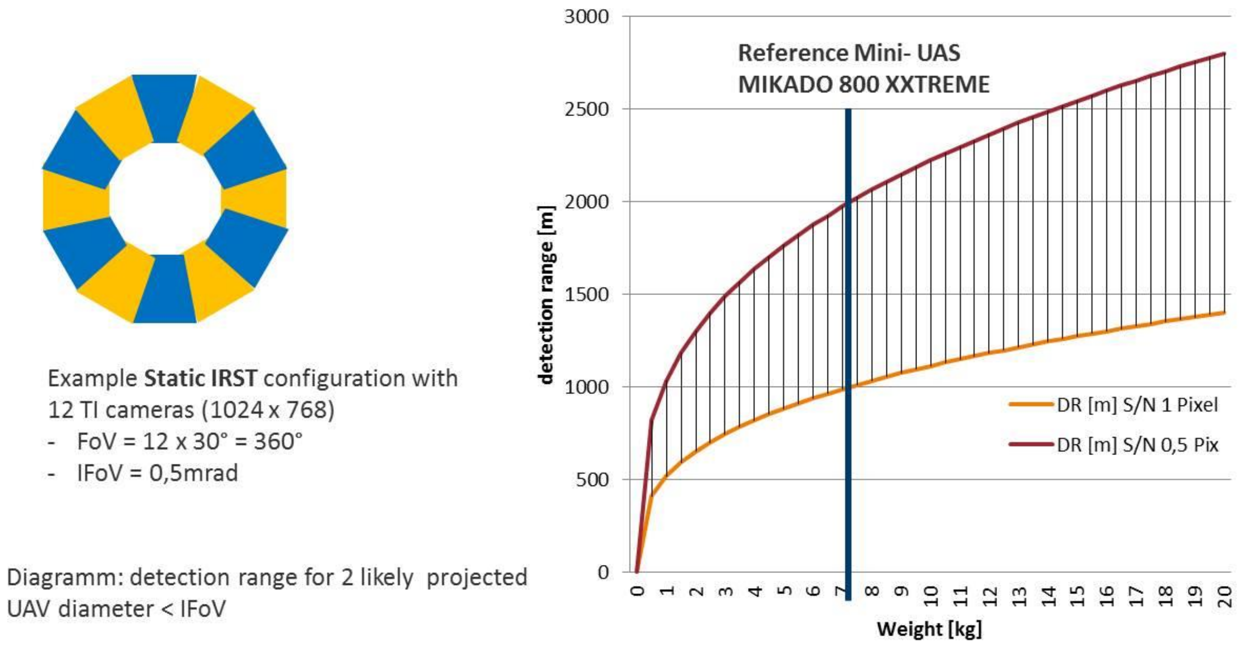


Figure 8: Example Static IRST

1.4.3 IR- NFoV- Sensor for Fix/Track & Identification.

The "Find" Sensor will assign the detected object direction to a verification sensor for object classification and threat identification. State-of-the-art EO observation and fire control platforms can typically be used for this task. The appropriate calculation method in accordance with STANAG 4347 is used for LSS-UAS detection, recognition and identification (D/R/I).

- IR- range calculation according STANAG 4347 (TRM3/4 method for Germany)
    - D/R/I = 1/3/6 line pairs/target = 2/6/12/horizontal Pixel on Target

- Following D/R/I example uses HAWK-2 & MERLIN TI (see ref. [1], page 32)

HAWK-2:
MW-IR (17mK NETD)
640 x 512 CdHgTe detector
2 deg FOV Lens
~0.055mrad per pixel resolution

MERLIN TI data:
MW-IR (17mK NETD)
1024 x 768 CdHgTe detector
2 deg FOV Lens
~0.034mrad per pixel resolution

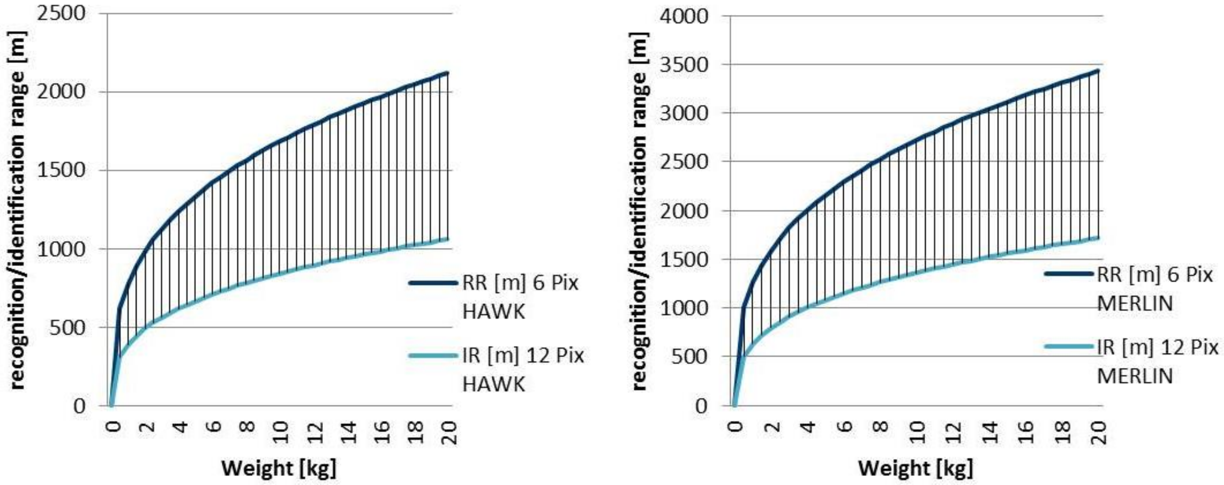


Figure 9: Recognition & Identification Ranges with cooled Thermal Imagers

The diagram above shows the recognition & identification ranges of the MW-IR TI with 2° NFOV and 640 (HAWK-2), or 1024 (MERLIN) horizontal pixel resolution. The real ranges may decrease depending on the optics, weather conditions, turbulence, background clutter, etc. A combination of an IRST sensor with the above type of verification TI camera satisfies the required DRI- process. An IRST detected object can be identified using a MW-, or LW-IR camera. If needed, specialized sensors like SWIR- gated viewing can assist target identifying under adverse weather conditions.

Typical, available EO- Fire Control platforms using TV, IR and LRF, like Rheinmetalls SEOSS (land vehicles) and MSP (naval applications) can be used for threat verification and fire control in all weather conditions. In static environment, i.e. asset and camp protection, the EO- platform needs no inertial stabilization. If tracking and fire control on the move is required stabilized platforms are needed and available.

Figure 10: left stabilized EO Sensor Suite for tanks and protected vehicles

Figure 11: right: stabilized Multi Sensor Platform for Naval & Air Defence applications

1.4.4 EO-Sensor Suite "Find to Identify"

The combination of an IRST sensor with a verification sensor in an EO-Sensor Suite allows the detection and verification of threats. With the described exemplary EO-Sensor Suite for Mini UAS a 360° detection range between 400m ≥ 800m can be achieved. In “Stationary Asset Defence” (SAD) possible threats, detected by FIRST, will be assigned to the co-located verification sensor. The verification sensor will track the threat with the TI-, or TV- Sensor for identification and will measure the distance with the integrated laser range finder (3D- Track). The NFoV gives a sufficient resolution for manual or semi-automatic identification. Two or more EO Sensor Suites can be integrated in a network to increase the surveillance area. For overlapping areas a sensor fusion is necessary to eliminate repeated measurements and to increase performance.

A sensor clustering concept may also include other non-EO Sensors into a Sensor station, i.e. Radar, ESM- and Acoustics.

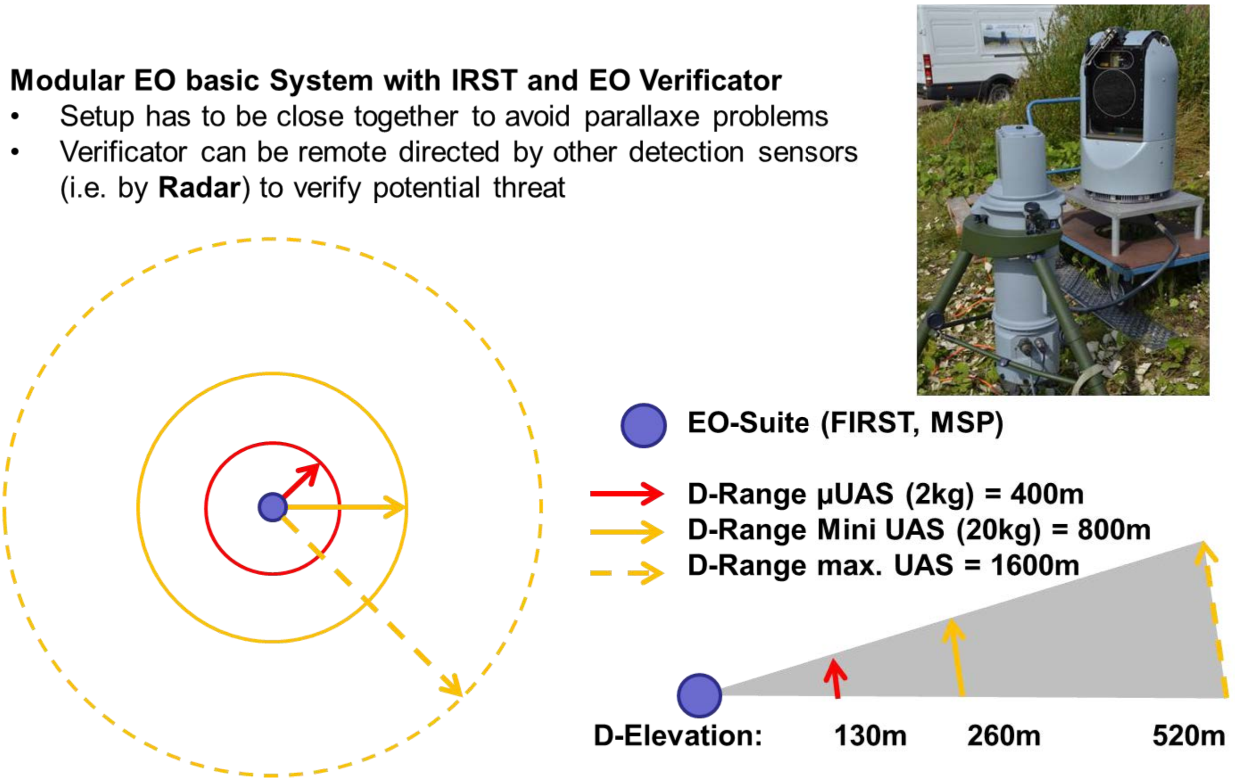


Figure 12: EO-Sensor Suite detection coverage area

2.0 LSS-UAS detection and verification results

During the last 3 years several security projects and trials have shown that detection and verification of LSS-UAS with an EO- Sensor Suite is feasible and helps the operator to clearly identify the possible threat.

Rheinmetall uses a mobile test platform on a Mercedes Sprinter with integrated extendable FIRST and MSP sensors (MEES), or an alternative configuration with static IRST and verificator (UMIT). The van integrated control unit includes all detection and tracking functions, displays the results to the operator, and/or transmits the data to associated recipients.

Figure 13: EO- Sensor Suite – mobile test platform MEES & UMIT

Reference of Security Projects and Threat Verification Trials, i.e.:

- EO: Several Airborne Threat Detection Trials, i.e. Spadeadam, UK, 2014
- EO/RF: C-UAS Trials, Baltic Sea, 2015, coordinator German MoD
- EO: Bristow 15, C-UAS Trials West Freugh/UK
- RF: W-band LSS- Detection Radar, CH, 2014, 2015
- EO/RF Maritime C-UAS Trials 2016, Rostock/Germany
- Security Service G7 Summit 2015, Elmau/GE
- Security Service World Economy Forum 2016, Davos/CH

The calculated detection rates have been achieved against a non-, or low- cluttered background of an UAS (i.e. blue, or grey sky, uniform surface, etc.). In a cluttered environment (i.e. structured background behind an UAS, like trees, houses, etc.) the detection range decreases, or the false alarm rate (FAR) will increase so much, that the verification process with the NFoV Sensor cannot be performed in time (The verification sensor can only verify and identify one possible threat per time).

Therefore it is necessary to add additional sensors (see NIAG studies SG-170[2], **SG-188[1]** and SG-200[3]), like Radars, PEL (passive emitter localization) and Acoustics to achieve the required early detection and pre- classification of LSS-UAS threats.

2.1 Vehicle Self Protection against UAS attack

International missions to prevent conflicts and crisis in asymmetric scenarios are increasing. Driver and operators in these military vehicles mostly have adverse sighting condition to the outside environment. Potential threats in the vehicles surrounding often cannot be seen according to occlusions by the vehicle. To enhance the survivability of human kind and to increase the effectiveness of the vehicles in their missions Rheinmetall has developed the Technology Demonstrator “SENSATION - Sensor-Effektor Network for Situational Awareness and Tactical Interoperability for Operational Needs” [7]. SENSATION covers a 360° infra-red and day sight close-up range surveillance, which is supported by intelligent image processing algorithms. Detected and identified objects can be used for an automatic assignment of the object position to the RCWS (Remote Controlled Weapon Station). The RCWS weapon sight uses a NFoV (Narrow Field of View) which enables the operator to identify the threat. With the use of the integrated LoS- Tracker the sighting line can control the weapon station and continuously follow and defeat the threat with the weapon on the platform.

Figure 14: SENSATION Technology Demonstrator

Requirements of operational mission systems on protected military vehicles:

- Networked Sensors and Effectors
- 360° Situational Awareness System
    - Panoramic Video Sights TV/IR with automatic Object Detection and Tracking
    - Acoustic Sniper Localization System, Laser Warning System, etc.
    - Detection & Tracking of Threats, Slew to Cue
- Automatic Line-of-Sight Tracking with Weapon Station (RCWS)
- Modularity and enhancements by Open Architecture (STANAG 4754 NGVA - NATO Generic Vehicle Architecture)

SENSATION was outlined to detect threats like vehicle and persons in urban and rural scenarios. With the increasing possibilities of LSS-UAS also these threats have to be detected and defeated.

In SENSATION a TV and IR 360° sight is already available and can be used for LSS-UAS detection and tracking. The examination of field trials showed, that the resolution of the used cameras (IFoV – Instant Field of View) need improvements for an earlier, in time detection, alarming and counter measuring. Ideas for an optimisation of image processing algorithms have been defined to reduce the false alarm rate.

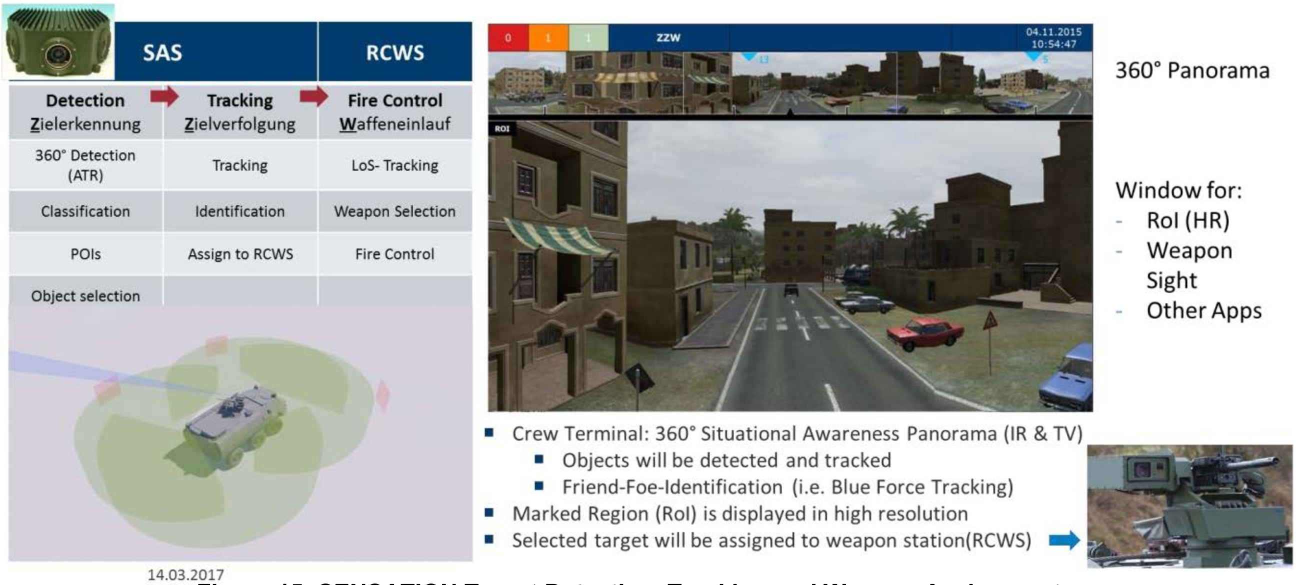


Figure 15: SENSATION Target Detection, Tracking and Weapon Assignment

Nevertheless in cluttered background environment additional sensors like Radar and PEL are necessary for a high and early detection rate and low false alarm rate.

The use of acoustic sensors for UAS detection/verification in a noisy vehicle environment is not recommended.

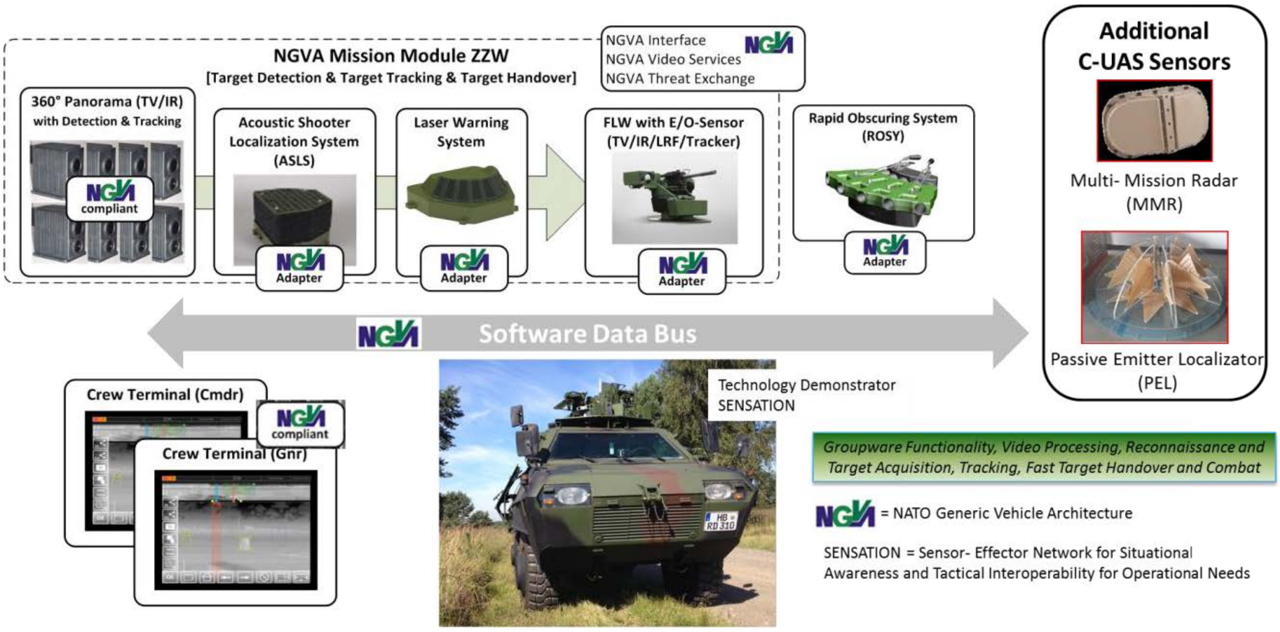


Figure 16: C-UAS Sensors for vehicles

2.2 Sensor Data Fusion

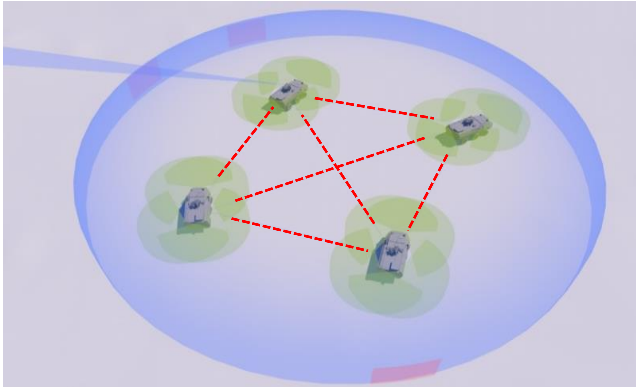
For C-UAS tasks mostly a sensor combination is necessary for a sufficient detection- and low false alarm-rate. Data from multiple sensors of the same type, or different types have to be combined, or fused. Main tasks for sensor data fusion are listed below.

Sensor Data Fusion of multiple identical sensors on a vehicle:

- Combination of sector sensors (i.e. 90° AZ Radar) to a consolidated 360° view
  - Fusion of multiple detections of the same object caused by sector overlap
  - Continuously object tracking in overlapping sensor sectors.
- Enhancement of detection probability and reduction of false alarm rate (FAR)
  - Sensor data assessment and weighted fusion of different sensor types
  - Fusion of features from different sensors to increase classification results (Radio pattern, RCS, µ-Doppler, EO, etc.)

Sensor Data Fusion across several distributed vehicles:

- Detection and Fusion of multiple detections of the same object by dislocated sensors.
- Increase of detection probability, position accuracy and reduction of FAR
- Localization of object position by triangulation (passive emitter localization)
- Support for fire control and UAS- counter measure (aim point designation, 3D- Tracking, etc.)



2.3 C-UAS self defence for vehicles

Army vehicles are typically equipped with a remote controlled weapon station (RCWS). These RCWS are mostly equipped with machine guns for self defence against troops and vehicles on the ground.
A typically RCWS comprises of a stabilized platform with fire control sensor and weapon. Possible payload configuration:

- weapon/ammunition types: MG 7.62mm, Gun .50, or 40mm grenade
- Fire control sensor
    - Coloured CCD- daylight camera
    - Thermal Imager
    - Laser Range Finder

Figure 17: RCWS example (Ref.: KMW)

Upgrades of already used self defence mission equipment, or additional LSS-UAS counter measure assets are necessary for legacy and new military vehicles. Results of German R&D studies recommend:

- Increase of the RCWS platform dynamics and performance
    - LSS-UAS are very agile and, according to the short time of notice from the UAS vehicle sensors, counter measures will be used in the near vicinity
- High precision, low latency control of the platform to assign line of fire to small UAS targets
    - Integration of Line-of-Sight tracking function with optimized low latency control loop
- Addition of new, alternative ammunition types with the capability to defend and/or destroy LSS-UAS, i.e.:
    - Pellets, air burst munition, etc.
    - High power electronic microwave (HPEM) effectors, high power laser (HEL), communication jammer, non-lethal effectors etc.

2.4 Recommendation for stationary and mobile Counter- UAS

General Recommendation for reliable detection and alerting of LSS-UAS:

- Sensor- Cluster with application specific selected active and passive sensors, including sensor data fusion
- Communication network between deployed sensor- clusters for stationary, or mobile application

C-UAS Recommendations regarding Mobile Force Protection (MFP):

- Incorporation of Size, Weight, Power and Costs (SWaPC) for additional or modified C-UAS Sensors and Equipment for autonomous protection of vehicles.
    - Improvements (C-UAS upgrade) of already available mission sensors and effectors are preferred versus costly enlargement of mission equipment.
- MFP system shall consist of a combination of Sensors, like active Radars, EO- Sensors and passive emitter localization (PEL-FPV), with successive Sensor Data Fusion
- A Network between mobile platforms (vehicle) increases the LSS-UAS localization by triangulation of UAS- bearing and sensor data fusion from distributed platforms
- A connection to the „local air picture“(blue force tracking) for protection of own flying assets (UAS).

2.5 Summary and Perspective

- IRST Sensors are suitable for 360° detection, tracking and alerting of LSS-UAS.
- In Combination with other sensor types (Radar, ESM, acoustics, etc.) efficient sensor cluster can be configured (see NIAG SG-188).
- Already mounted sensors and effectors on vehicles for self-defence are not appropriate for counter LSS-UAS tasks and have to be upgraded or extended.
    - Size, Weight Power and Costs (SWaPC) have to be considered for mobile force protection.
- Modular, NGVA (STANAG 4754) compliant vehicle mission systems provide easy extension possibilities to integrate necessary C-UAS functions.
- Network and Fusion of sensors on a platform, or on distributed platforms are required for a high detection probability with low false alarm rate.
- Verification, identification and also fire control of LSS-UAS threats need a remote controlled, agile EO- platform with high resolution field of view and image processing assistance.
- For early detection convenient smart sensors with increased performance and enhanced image processing algorithms are still required.

REFERENCES

[1] **NIAG SG-188:** FINAL REPORT OF NIAG SG-188 STUDY ON GBAD SENSOR MIX OPTIMISATION STUDY FOR EMERGING THREATS

[2] **NIAG SG-170:** FINAL REPORT OF NIAG SG170 ON ENGAGEMENT OF LOW, SLOW AND SMALLAERIAL TARGETS BY GBAD, 16th September 2013

[3] **NIAG SG-200:** FINAL REPORT OF NIAG SG-200 STUDY ON LOW, SLOW AND SMALL THREAT EFFECTORS, draft – will be available August 2017

[4] **DARPA-PS-17-01:** PROGRAM SOLICITATION DARPA-PS-17-01 for MOBILE FORCE PROTECTION OCTOBER 26, 2016.

[5] **LSS-ZZW,** F&T- Studie LSS-UAV- Aufklärung in NGVA-ZZW, Rheinmetall Defence Electronics R&T Study for BAAINBw, 2015

[6] **R&D Counter-UAS Study,** F&T Studie Counter-UAS, 2016 – 2019, BAAINBw, Status Report 2016

[7] **SENSATION, Final Report** BL 8445 T016 TB, 05.12.2014, Optimierung der Sensorsuite ZZW SENSATION