ROYAL MILITARY ACADEMY
ROBOTICS & AUTONOMOUS SYSTEMS
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# Drone warfare seminar

# Welcome & Introduction

**Agenda:**

- Speaker introduction
- SitRep on drone warfare
- Future trends & innovations in drone & counter-drone technology
- How can we adapt our DOTMLPF to this new era?
- Training the future generations
- Discussion & Conclusions

# Welcome & Introduction

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- SitRep on drone warfare
- **Future trends & innovations in drone & counter-drone technology**
- How can we adapt our DOTMLPF to this new era?
- Training the future generations
- Discussion & Conclusions

# Speaker introduction

- Geert De Cubber
- Member of Royal Military Academy (RMA): University of Belgian Defence
- Head of Robotics & Autonomous Systems (RAS) unit: https://mecatron.rma.ac.be/

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# Speaker introduction

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- Member of Royal Military Academy (RMA): University of Belgian Defence
- Head of Robotics & Autonomous Systems (RAS) unit: https://mecatron.rma.ac.be/
- Project Coordinator of EU project COURAGEOUS: https://courageous-isf.eu/

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# SitRep on drone warfare

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- Nomenclature:

NATO UAS CLASSIFICATION

| Class | Category | Normal Employment | Normal Operating Altitude | Normal Mission Radius | Primary Supported Commander | Example Platform |
|---|---|---|---|---|---|---|
| Class III (> 600 kg) | Strike/ Combat* | Strategic/National | Up to 65,000 ft | Unlimited (BLOS) | Theatre | Reaper |
| | HALE | Strategic/National | Up to 65,000 ft | Unlimited (BLOS) | Theatre | Global Hawk |
| | MALE | Operational/Theatre | Up to 45,000 ft MSL | Unlimited (BLOS) | JTF | Heron |
| Class II (150 kg - 600 kg) | Tactical | Tactical Formation | Up to 18,000 ft AGL | 200 km (LOS) | Brigade | Hermes 450 |
| Class I (< 150 kg) | Small (>15 kg) | Tactical Unit | Up to 5,000 ft AGL | 50 km (LOS) | Battalion, Regiment | Scan Eagle |
| | Mini (<15 kg) | Tactical Subunit (manual or hand launch) | Up to 3,000 ft AGL | Up to 25 km (LOS) | Company, Platoon, Squad | Skylark |
| | Micro** (<66 J) | Tactical Subunit (manual or hand launch) | Up to 200 ft AGL | Up to 5 km (LOS) | Platoon, Squad | Black Widow |

*Note: In the event the UAS is armed, the operator should comply with the applicable Joint Mission Qualifications in ATP-3.3.7 (STANAG 4670) and the system will need to comply with applicable air worthiness standards, regulations, policy, treaty, and legal considerations.

**Note: UAS that have a maximum energy state less than 66 Joules are not likely to cause significant damage to life or property, and do not need to be classified or regulated for airworthiness, training, etc. purposes unless they have the ability to handle hazardous payloads (explosive, toxins, chemical/

# SitRep on drone warfare

- Drones are formidable assets (for good, but also for bad causes)
- Drone technology is now widely available
- However, a single drone is capable of causing great harm
- Weaponisation of the systems (happening now in Ukraine) could aggravate this

# SitRep on drone warfare: Nagorno-Karabakh

- Azerbaijan's effective use of Turkish Bayraktar TB2 drones and Israeli-made loitering munitions (Harop) was a game-changer. These drones were pivotal in destroying Armenian tanks, artillery, and air defense systems

- The conflict demonstrated how a technologically inferior force could gain superiority through strategic use of drones

# SitRep on drone warfare: Nagorno-Karabakh

**Strategic and Tactical Advantages:**

- Drones provided Azerbaijan with superior surveillance, real-time intelligence, and the ability to conduct precision strikes, thereby altering the operational dynamics and leading to a swift victory.

- The **psychological** impact on Armenian forces, constantly under threat from unseen aerial strikes, played a significant role in the conflict's outcome

# SitRep on drone warfare: Ukraine

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**Widespread Use of Drones:**

- **Ukraine:** Leveraged a variety of drones, including commercial, DIY, and military-grade systems like the Turkish TB2 Bayraktar. These drones have been crucial in reconnaissance, targeting artillery, and direct strikes.

- **Russia:** Employed drones such as the Orion and Orlan-10 for surveillance and the Iranian Shahed-136 for loitering munitions and strategic strikes

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# SitRep on drone warfare: Ukraine

**Tactical Innovations:**

- Ukraine has been innovative with commercial and DIY drones, using FPV racing drones for kamikaze attacks and leveraging volunteer networks for rapid deployment and modification of these systems.

- Both sides have engaged in rapid innovation cycles, with Russia quickly adapting Ukrainian tactics to maintain a competitive edge

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# SitRep on drone warfare: Ukraine

**Impact on the Battlefield**:

- Drones have compressed the kill chain, enabling faster decision-making and more precise targeting.

- Both sides have used drones to conduct deep strikes beyond the front lines, targeting critical infrastructure and disrupting supply chains

# SitRep on drone warfare: Ukraine

**Countermeasures and Electronic Warfare:**

- Extensive use of electronic warfare to jam drone signals and physical countermeasures like netting and drone-on-drone combat have been observed.

- Both parties are developing and deploying counterdrone technologies, including software for tracking and targeting drone operators

# SitRep on drone warfare: Lessons learned

**Accessibility and Affordability:**

- Commercial and DIY drones have lowered the barrier to entry, allowing even smaller or less technologically advanced forces to deploy effective aerial capabilities.

- The cost-effectiveness of commercial drones has enabled their widespread use, creating new tactical possibilities at a lower cost compared to traditional military systems

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# SitRep on drone warfare: Lessons learned

**Innovative Tactics and Rapid Adaptation:**

- Conflicts in Ukraine and Nagorno-Karabakh have shown that rapid innovation and adaptability are crucial. Both sides in Ukraine quickly adapted to each other's drone tactics, creating a dynamic battlefield environment.

- Volunteer and civilian contributions to drone warfare, especially in Ukraine, highlight the importance of non-state actors in modern conflicts

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# SitRep on drone warfare: Lessons learned

**Counterdrone Strategies:**

- Effective counterdrone measures, including electronic warfare and physical interception techniques, are vital. The ability to neutralize enemy drones can significantly alter the balance of power on the battlefield.
- Developing resilient and adaptive countermeasures is essential to maintaining operational effectiveness against a drone-equipped adversary

# SitRep on drone warfare: Lessons learned

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**Strategic Implications:**

- The strategic use of drones for deep strikes and disruption of enemy logistics and infrastructure has been a key factor in modern conflicts
- Drones have reshaped traditional concepts of air superiority, allowing smaller nations to challenge more powerful adversaries effectively

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# Future Trends and Innovations: Drones

## Artificial Intelligence and Machine Learning Integration

- **Autonomous Operations**: Drones will increasingly leverage AI and ML for autonomous navigation, target identification, and decision-making, reducing the need for human operators, GNSS reception, and enabling more complex missions.
- **Swarm Intelligence**: AI will enable the coordination of drone swarms, where multiple drones operate as a cohesive unit to execute coordinated attacks, reconnaissance, and other missions

# Future Trends and Innovations: Drones

### Enhanced Surveillance and Reconnaissance Capabilities

- **Advanced Sensors**: Future drones will be equipped with improved sensors, including hyperspectral and multispectral cameras, to enhance detection capabilities and gather more detailed intelligence.
- **Persistent Surveillance**: Development of high-endurance drones capable of long-duration flights will provide continuous surveillance over extended periods, crucial for real-time intelligence

# Future Trends and Innovations: Drones

**Miniaturization and Stealth Technologies**

- **Micro and Nano Drones**: Smaller drones will be developed for covert operations, capable of infiltrating buildings, urban environments, and other restricted areas without detection
- **Low Observable Technologies**: Future drones will incorporate stealth technologies to reduce radar, thermal, and acoustic signatures, making them harder to detect and counter

# Future Trends and Innovations: Drones

## Improved Payload Capabilities

- **Versatile Payloads**: Future military drones will carry a variety of payloads, from precision-guided munitions to electronic warfare modules, enhancing their versatility in different combat scenarios.
- **Modular Design**: Modular drones will allow for quick changes in payloads based on mission requirements, increasing operational flexibility

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# Future Trends and Innovations: Drones

**Long-Range and High-Endurance Drones**

- **Extended Range**: Development of drones with longer operational ranges to conduct deep strikes and extended reconnaissance missions far from the home base.
- **Solar and Hybrid Power**: Use of solar and hybrid propulsion systems to significantly extend flight times and reduce dependency on traditional fuel sources

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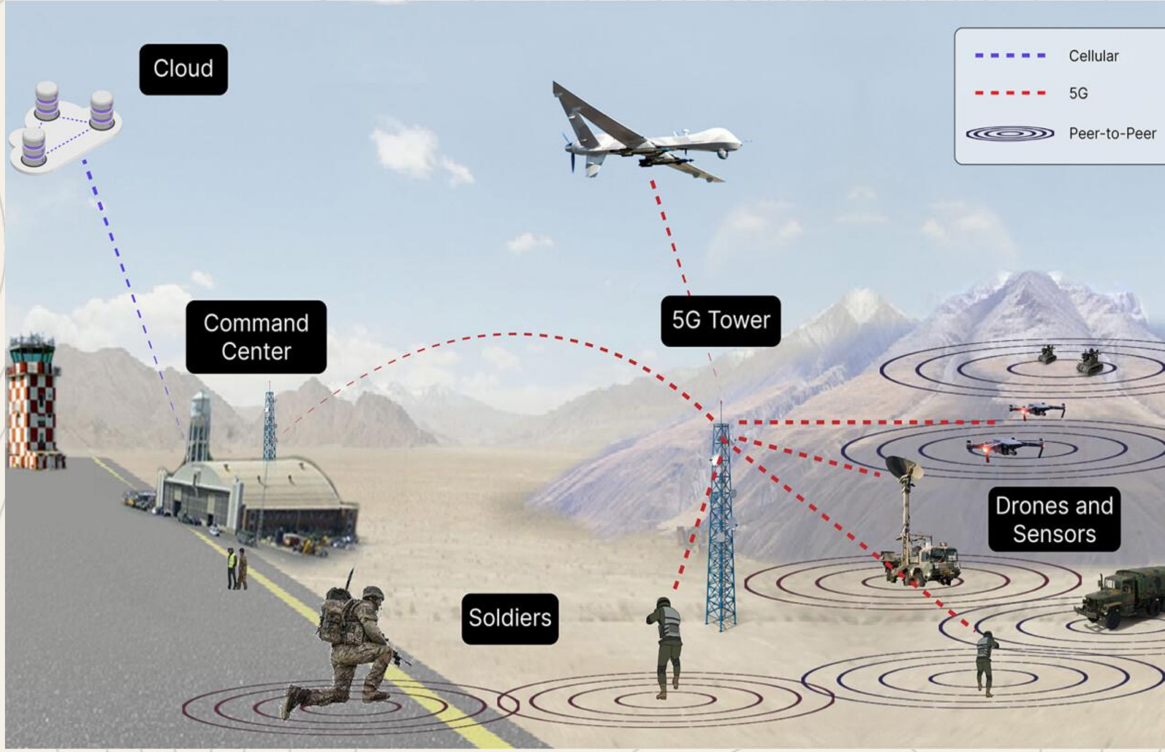
# Future Trends and Innovations: Drones

**Network-Centric Warfare**

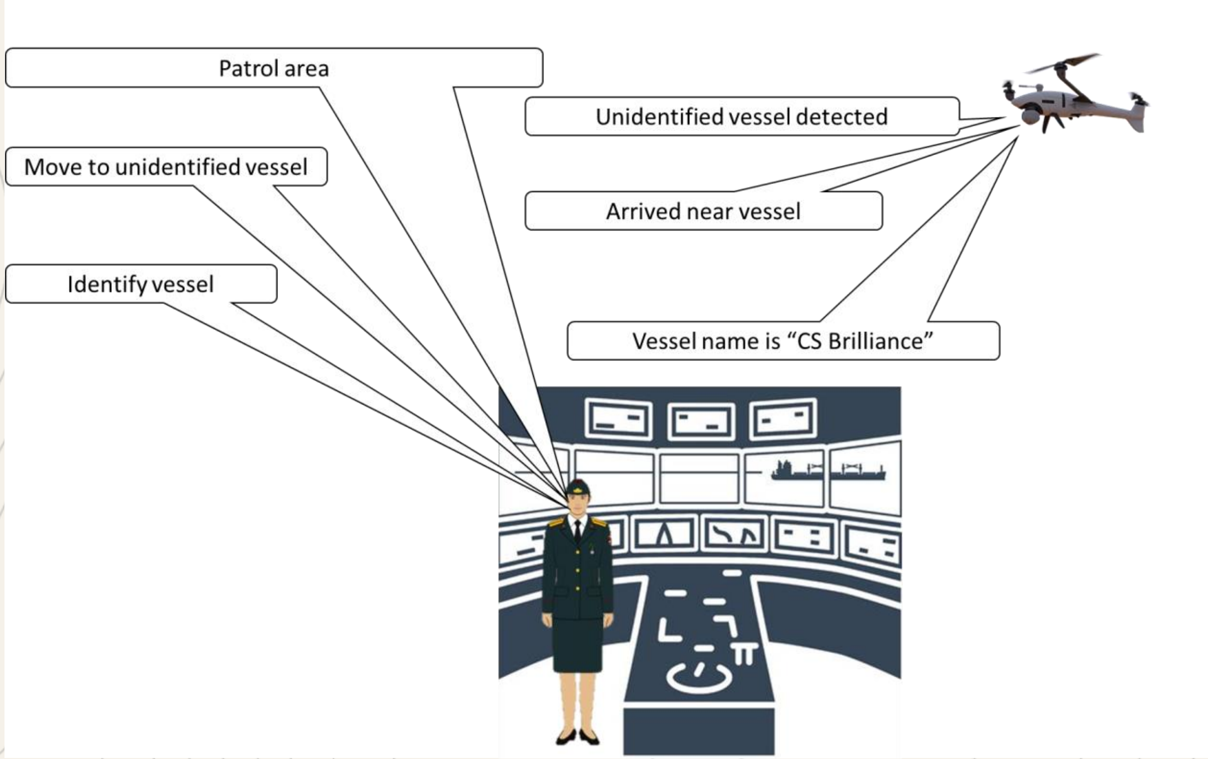
- **Integration with Military Networks**: Future drones will be integral to network-centric warfare, sharing real-time data with other assets, enhancing situational awareness, and enabling coordinated multi-domain operations.
- **Cloud-Based Operations**: Leveraging cloud computing to process vast amounts of data collected by drones, providing actionable intelligence faster and more efficiently



# Future Trends and Innovations: Drones

## Human-Machine Teaming

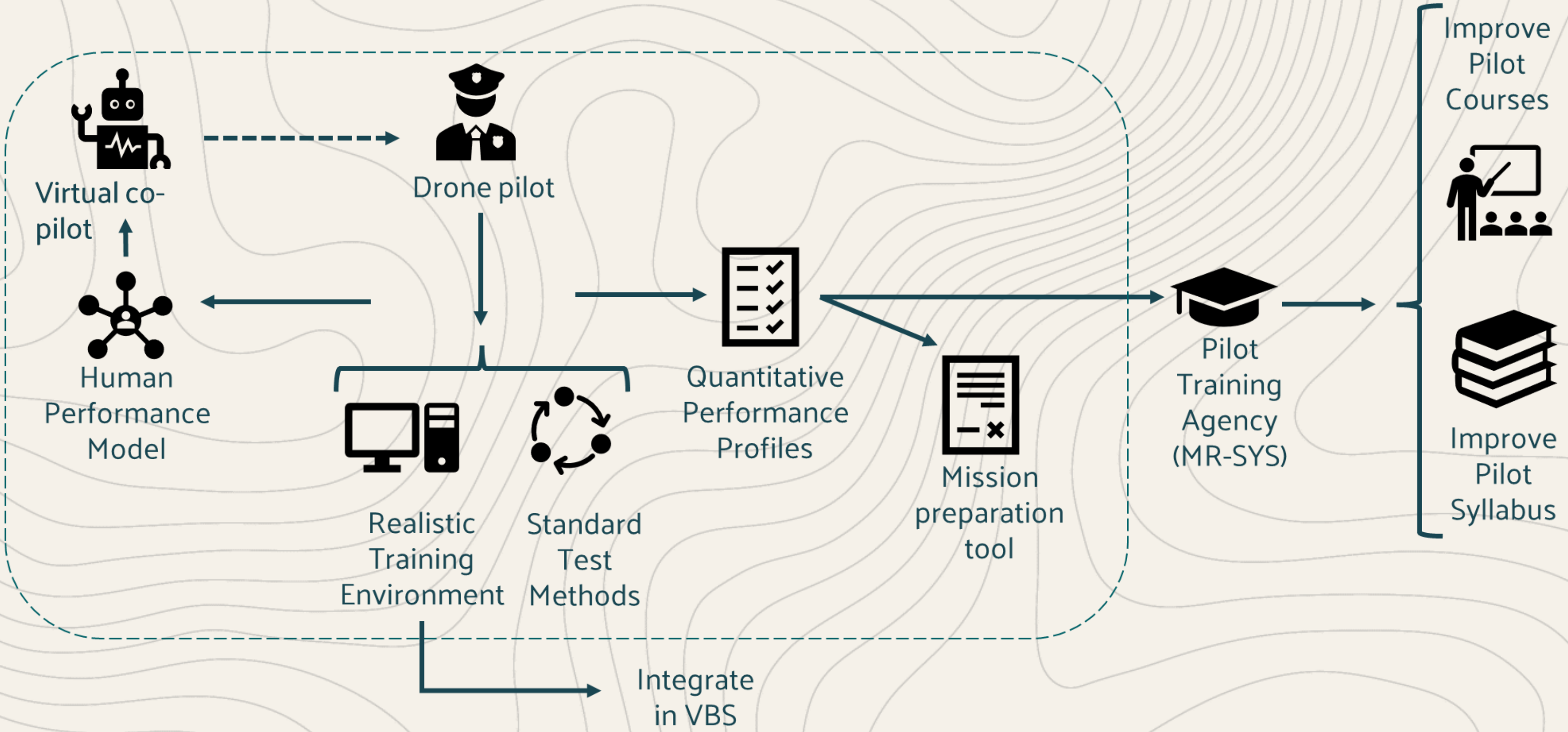
- **Collaborative Autonomy**: Development of systems where drones and human operators work together seamlessly, with drones performing dangerous tasks while humans provide strategic oversight.
- **Enhanced User Interfaces**: Improved interfaces for drone operators, including augmented reality (AR) and virtual reality (VR), will provide better situational awareness and control



# Future Trends and Innovations: Drones

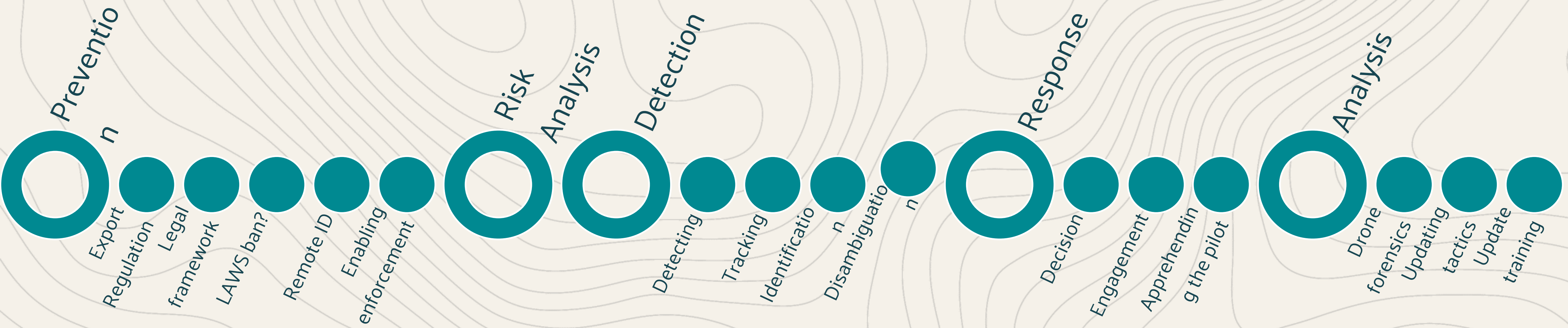
Training of drone operators

- Human Performance modelling.
- Standardised Test Methods
- Training in simulation
- Quantitative performance evaluation




# Future Trends and Innovations: Counter-drone

- The Counter-Drone kill-chain

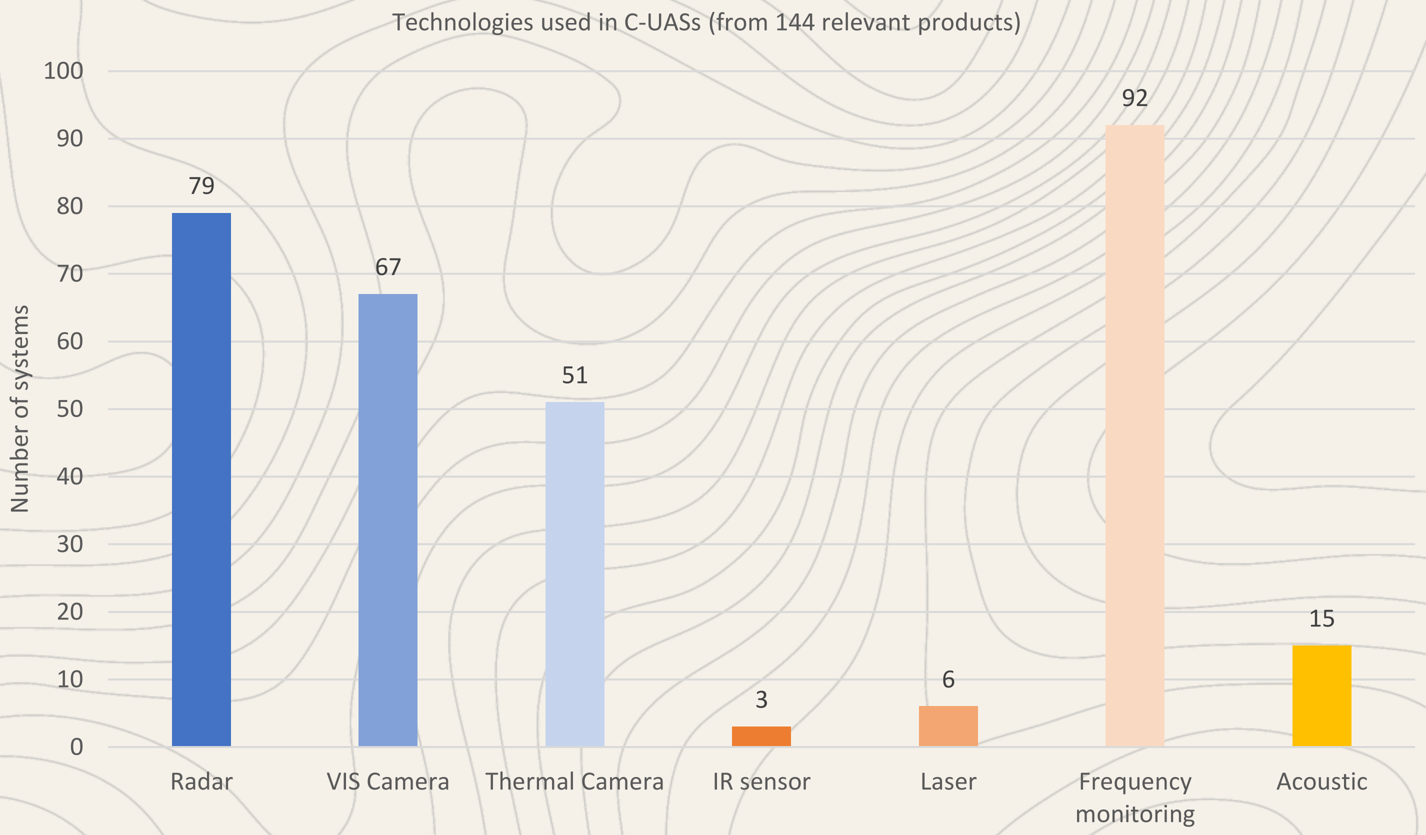


# Future Trends and Innovations: Counter-drone

Current technologies:

- Visual cameras
- Thermal cameras
- Radio Frequency Monitoring
- Acoustic sensing
- RADAR
- LiDAR

- Combinations of the above

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# Future Trends and Innovations: Counter-drone

- Visual cameras
- Thermal cameras
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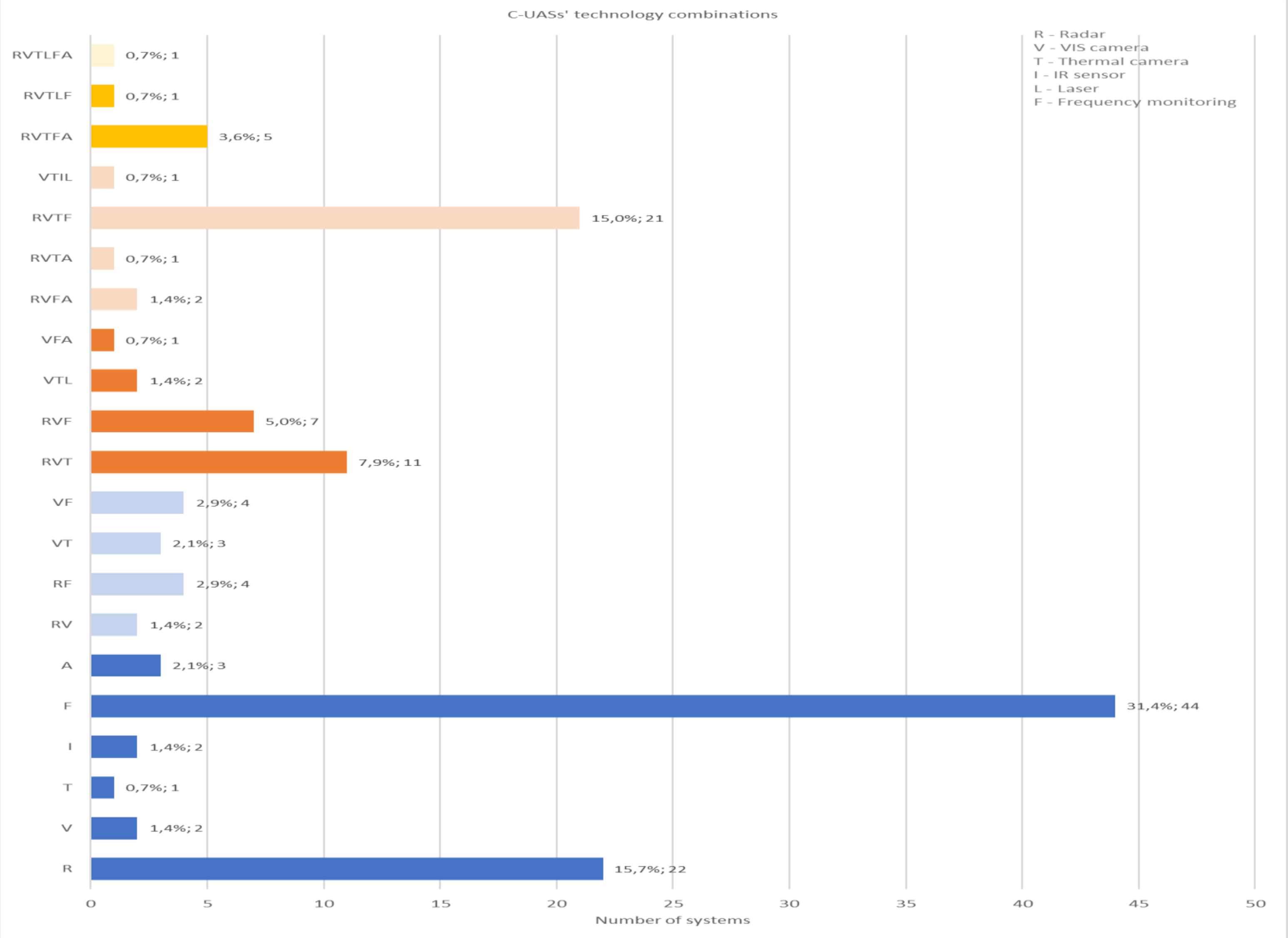
- **Combinations of the above:**

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# Visual Cameras

**Advantages:**

- Relatively cheap solution (at first sight …)
- Very good for Identification or for assessing the threat level (payload)
- Passive system
- Can ideally detect any drone in VLOS

# Visual cameras - disadvantages

- Operation at night or in low light conditions
- Limited resolution ➔ limited field of observation
- The ability to indicate the distance of an object is limited
- It is difficult to indicate the coordinates of the object.
- The dynamics of image lighting (clouds, sun, etc.) significantly affect the detection of the object in the image.
- Light reflections from dirt on the lens disqualify the solution from use
- Slow camera pan tilt mechanism may not keep up with the tracking of the drone.
- There is a possibility of dazzling the camera.
- High computing power (AI) is required to recognize a drone.
- Requires VLOS ➔ difficult in urban environment

# Visual + IR cameras

- **Operation at night or in low light conditions**
- Limited resolution ➔ limited field of observation
- The ability to indicate the distance of an object is limited
- It is difficult to indicate the coordinates of the object.
- The dynamics of image lighting (clouds, sun, etc.) significantly affect the detection of the object in the image.
- Light reflections from dirt on the lens disqualify the solution from use
- Slow camera pan tilt mechanism may not keep up with the tracking of the drone.
- There is a possibility of dazzling the camera.
- High computing power is required to recognize a drone.
- Requires VLOS ➔ difficult in urban environment

# Visual + IR cameras - disadvantages

- For operation at large distances, high-quality lenses and PTZ systems are required ➔ expensive
- Heat reflections
- Dependence on weather phenomena: fog, snow, clouds and rain
- Limited resolution + hi-res IR
- Ability to indicate the distance of an object is limited only to predictions from the calculation of the potential size of the object.
- Cameras can be blinded
- Objects flying low over a large sunny surface (asphalt, concrete) in long-range imaging with a thermal imaging camera have artifacts from heated air.

# Visual + IR cameras: conclusions

- Cameras are **almost never** used as only sensor for detection (you cannot cover the whole sky)
- Cameras are sometimes used to assist with the tracking
- Cameras are **very often** used for identification, as they have the potential to provide a clear picture of the drone to the human operator

# Acoustic sensing

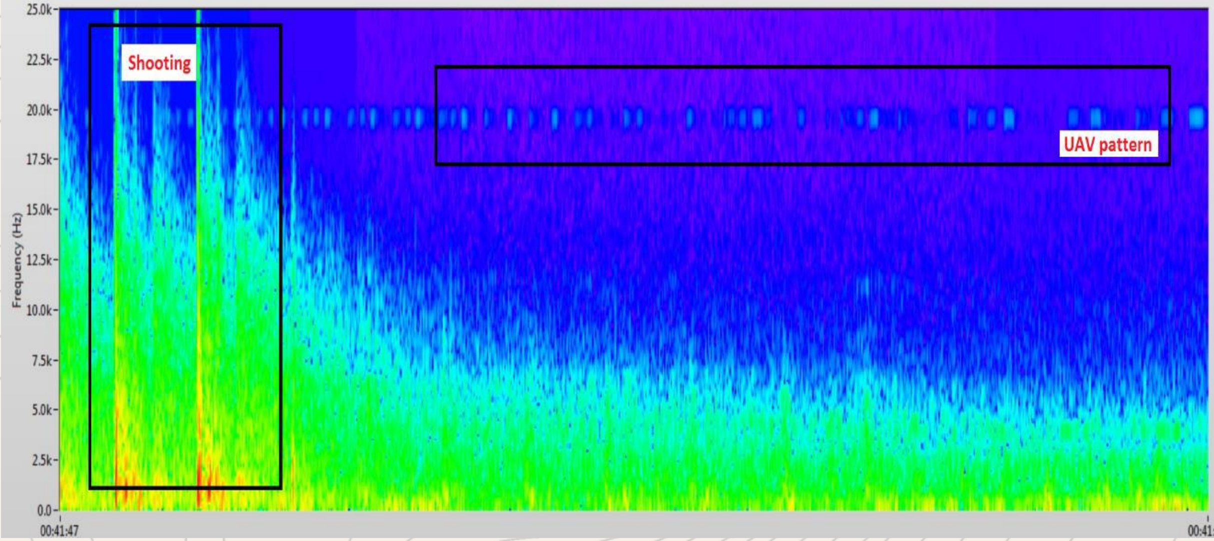
**Modus operandi:**

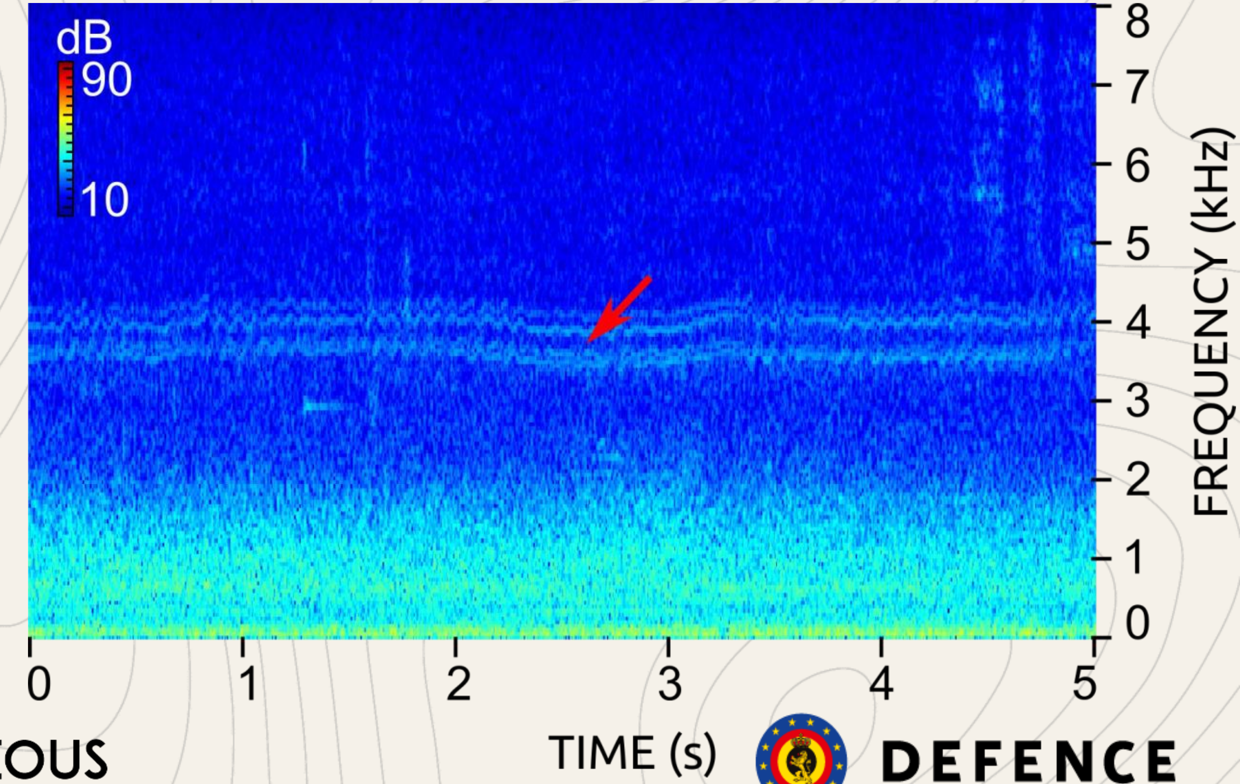
- Array of directional microphones
- Acoustic analysis
- Triangulation

# Acoustic sensing

## Modus operandi:

- Array of directional microphones
- **Acoustic analysis**
- Triangulation

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# Acoustic sensing - Conclusions

- Acoustic sensors can be used as a low-cost sensor to check whether there is a drone intrusion at some non-urban installation, if it is not a problem that the drone is only spotted at the very last moment.

- Example: non-urban prison

- In reality: not so much used anymore, due to reliability problems in urban environments (where most of the problems/needs are)

# RADAR

Idea:

- Adapt traditional RADAR system from aeronautics domain to detect also drones

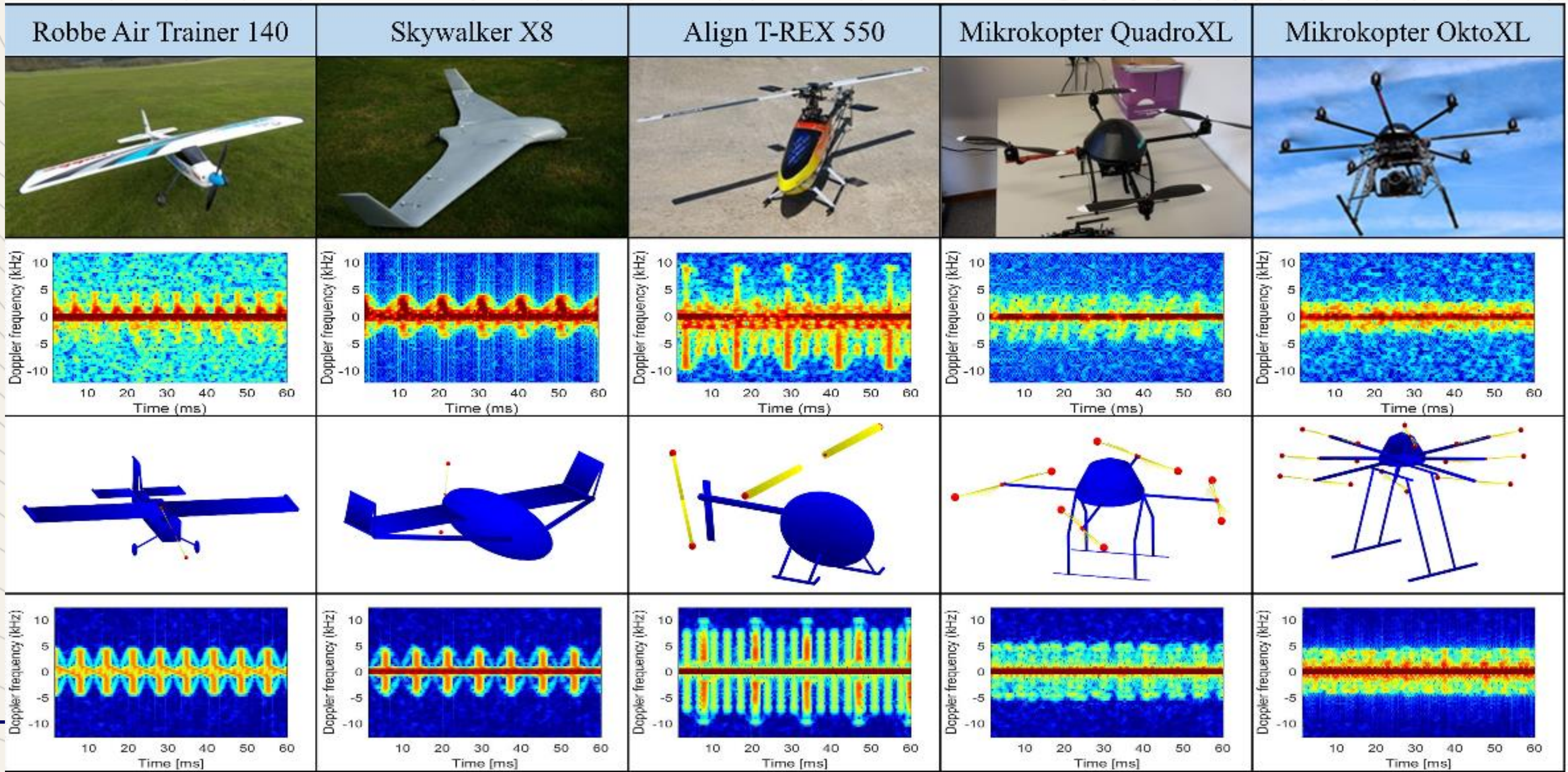
- Often also evolution from bird-detection RADARs

- Can use:
    - X-band: 8-12 GHz
    - K-band: 24 GHz
    - Ku-band: 13.45 GHz
    - S-band: 2-4 GHz

# RADAR

Idea:

- Try to find drone in RADAR spectrogram
- Detection: OK
- Classification: Very Hard
- Based on forward-backward rotor motion



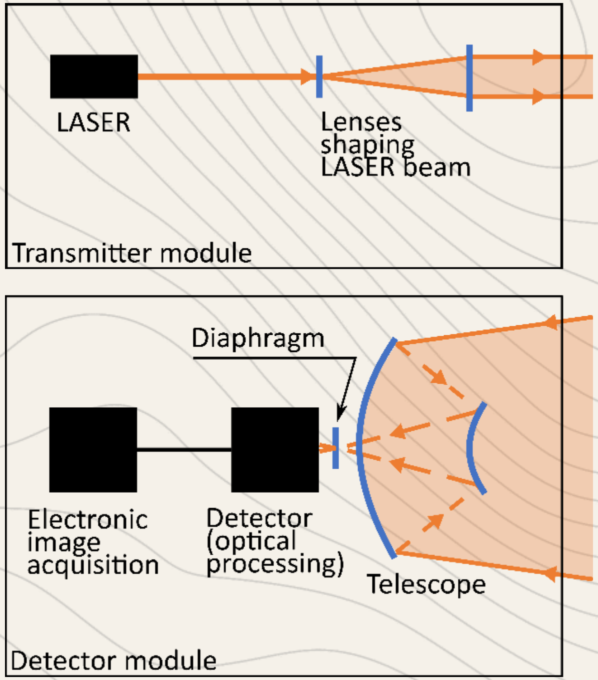
# RADAR - Conclusions

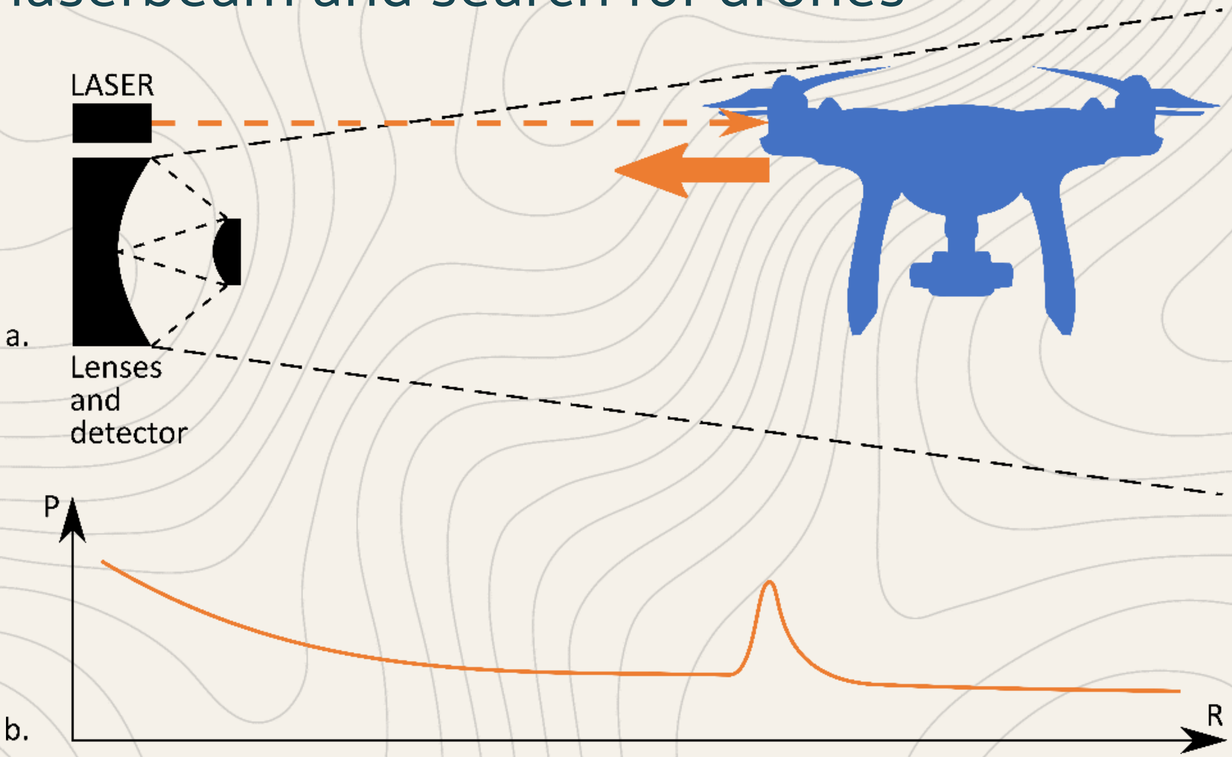
- RADAR is a very good sensing modality, often used in sophisticated systems as a base sensor to do a **first** detection of potential threats.
- For classification, this result is then often combined with other sensing modalities, as classification and identification is more difficult with RADAR

# LIDAR

**Idea:**

- Scan the airspace (in 3D) with a laserbeam and search for drones

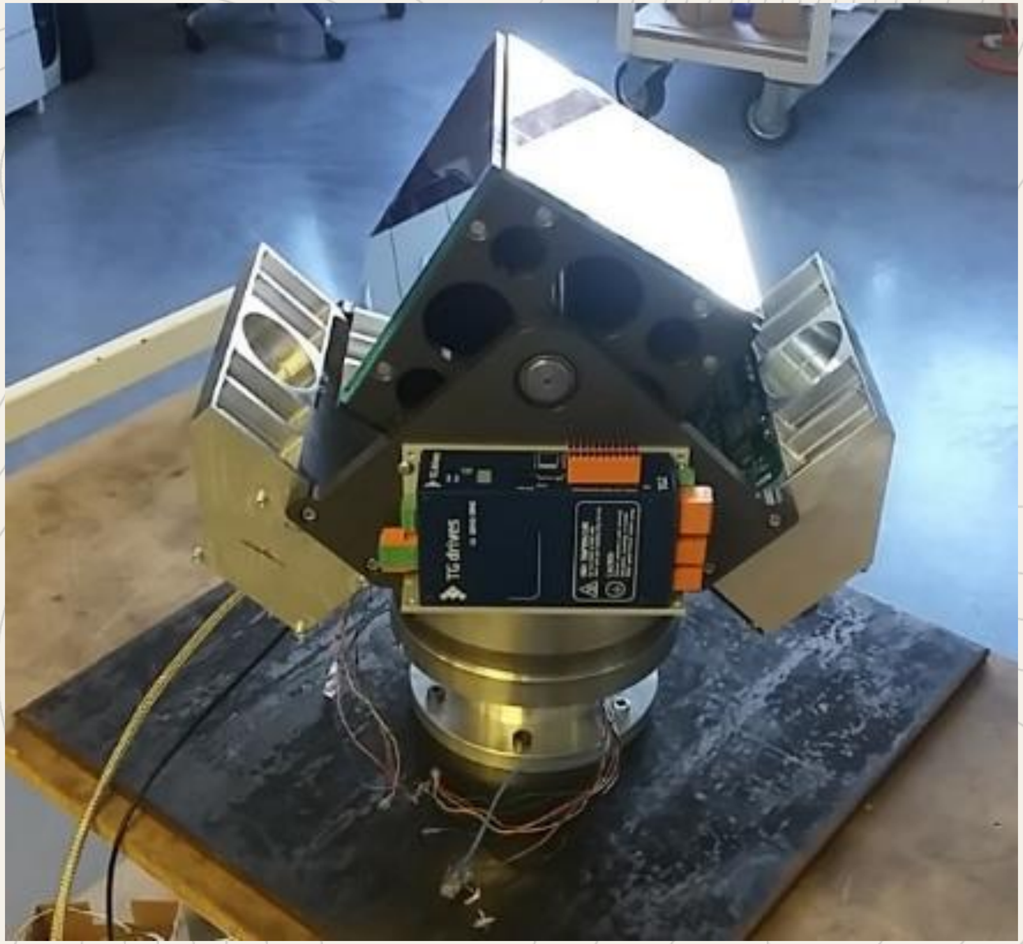


# LIDAR - Conclusions

- The use of LIDAR systems is at this moment still limited, due to the limited range (several 100m).

- They are promising due to their capability of ultra-precise localization, which makes them ideally suited to be paired with a neutralization system.



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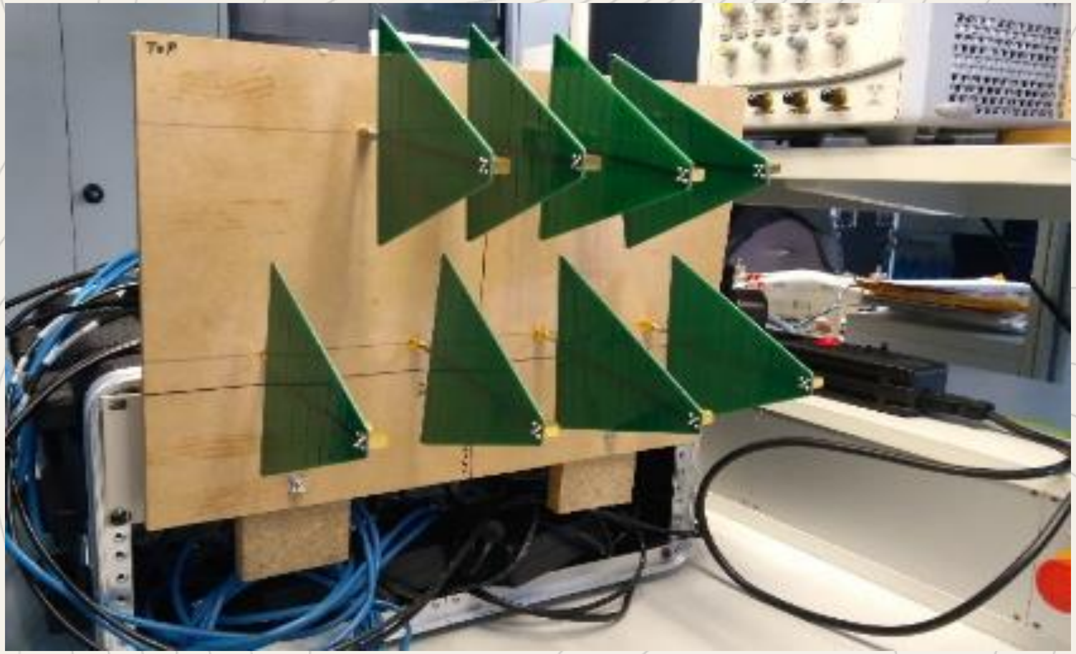
# Radio Frequency Monitoring

**Idea:**

- Use Software Defined Radio receivers to intercept radio signals (video, telemetry, control link, ...) sent from the drone to the pilot (or vice versa) and decide based on that whether a drone is present

- RF pattern recognition via database matching of known systems



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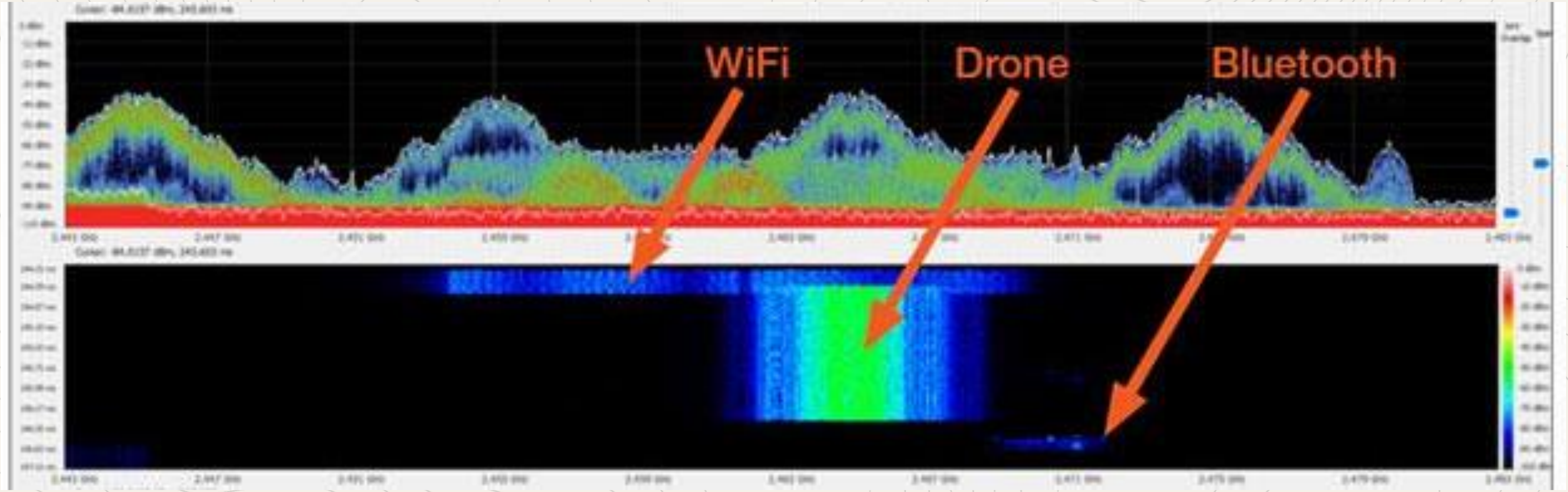
# Radio Frequency Monitoring

Idea:



# Radio Frequency Monitoring - Conclusions

- RF monitoring is a very good modality that is widely used at this moment, as it pairs an affordable price with a reasonable detection range
- Moreover, the capability to locate the pilot is unique, which is highly important

However, the future of this modality faces many challenges:

- How to deal with non-standard drones that are not in the database?
- How to improve localization accuracy (required if to be coupled with neutralization)?
- How to deal with more autonomous systems?
- How to deal with 5G/6G drones?

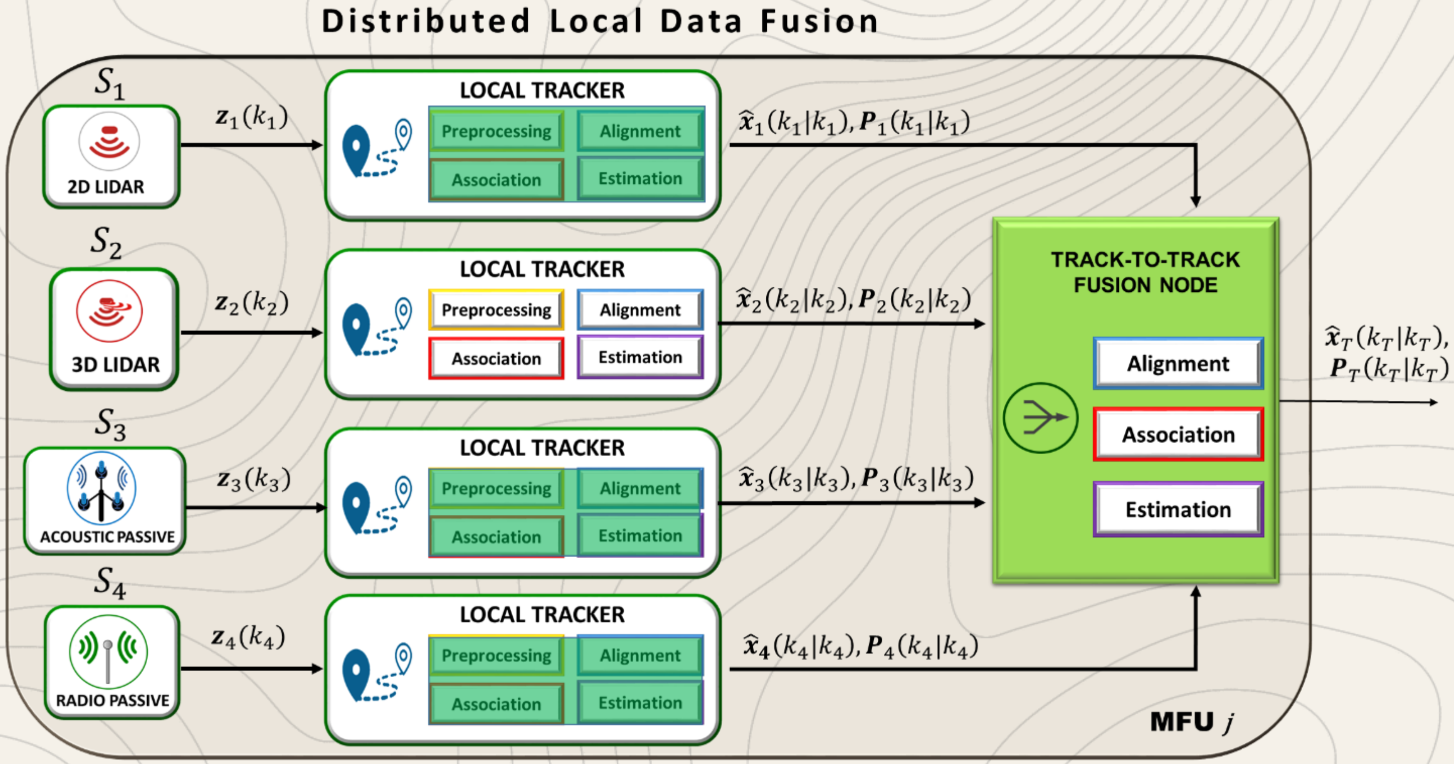
# Towards a 5G / 6G future?

- In the future, mobile phone operators may become the drone detection companies, as they are the only ones to have access to the raw comms data enabling to discriminate between drones and other 5G/6G users.

# Sensor fusion modalities

- No silver bullet ➔ combination of modalities required ➔ Data fusion

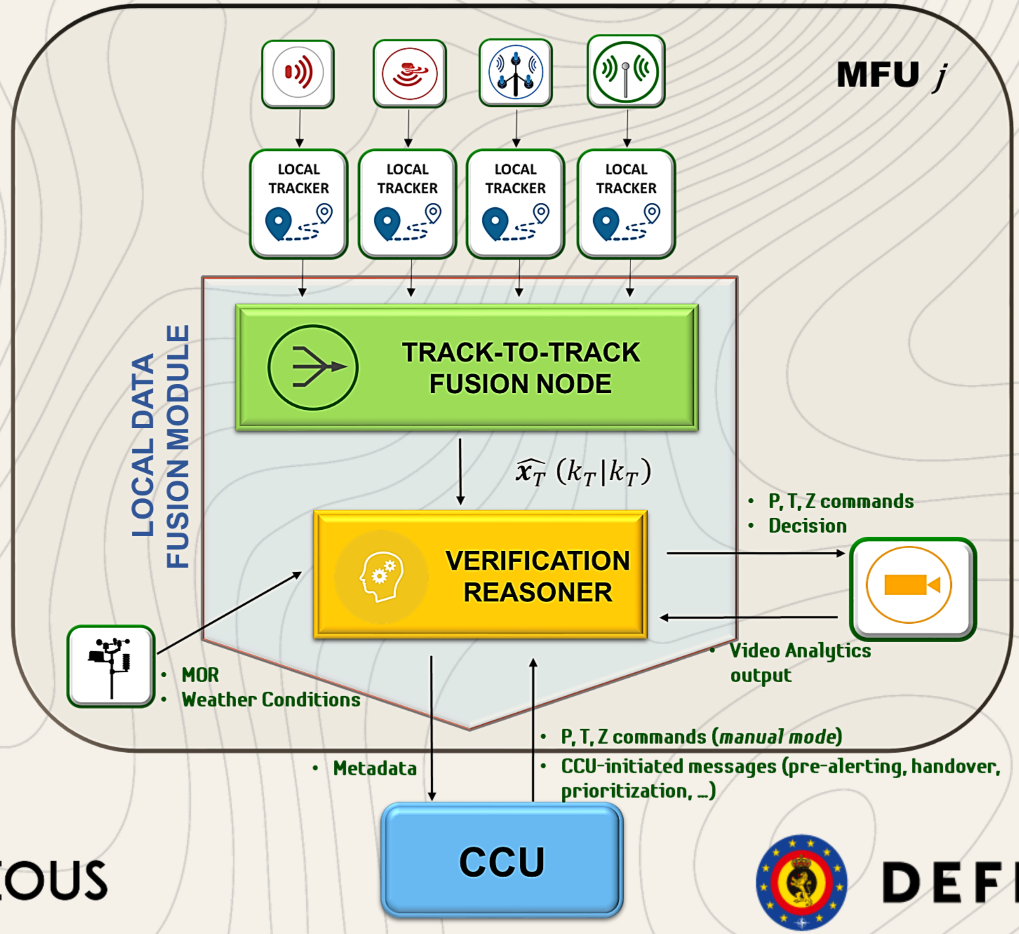
- Often based on some form of Bayesian reasoning (Kalman filters)



# Sensor fusion modalities

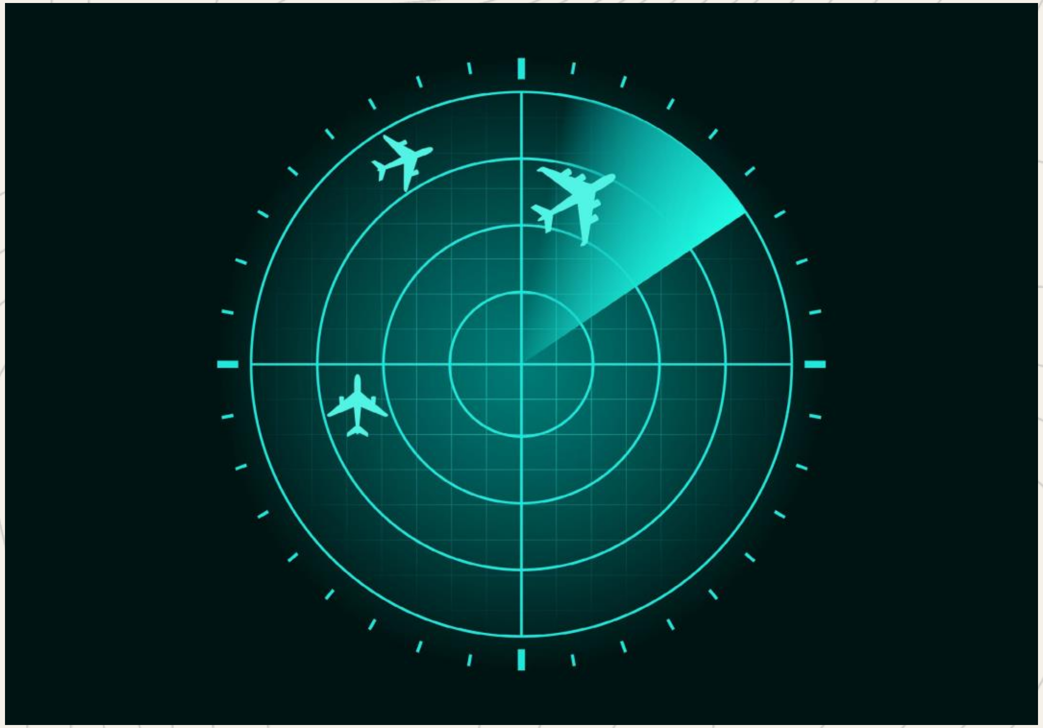
- No silver bullet ➔ combination of modalities required ➔ Data fusion

- Often RADAR / LIDAR / RF / Acoustic sensors give a first track estimate that then needs to be verified with a Pan-Tilt-Zoom Visual/Thermal camera, so this needs to be incorporated in the control process



# Sensor fusion modalities

- How to make several detectors speak to one another? ➔ SAPIENT
- Sensing for Asset Protection with Integrated Electronic Networked Technology
- Developed by the UK's MoD
- Open standard for fusion & integration of autonomous sensory information into a single integrated picture.
- Will likely become NATO Standardisation Agreement (STANAG) standard for C-UAS
- https://www.gov.uk/guidance/sapient-autonomous-sensor-system



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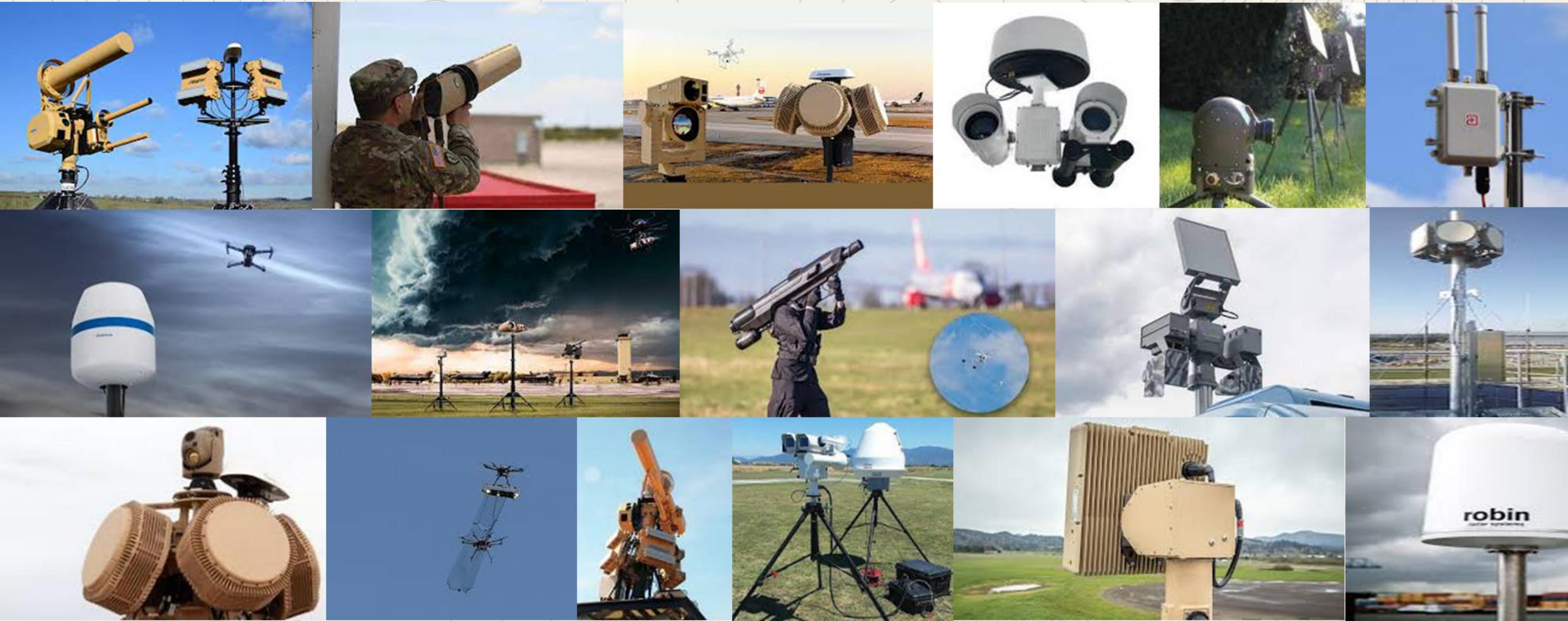
# DTI performance assessment

- What system is best for my use case?

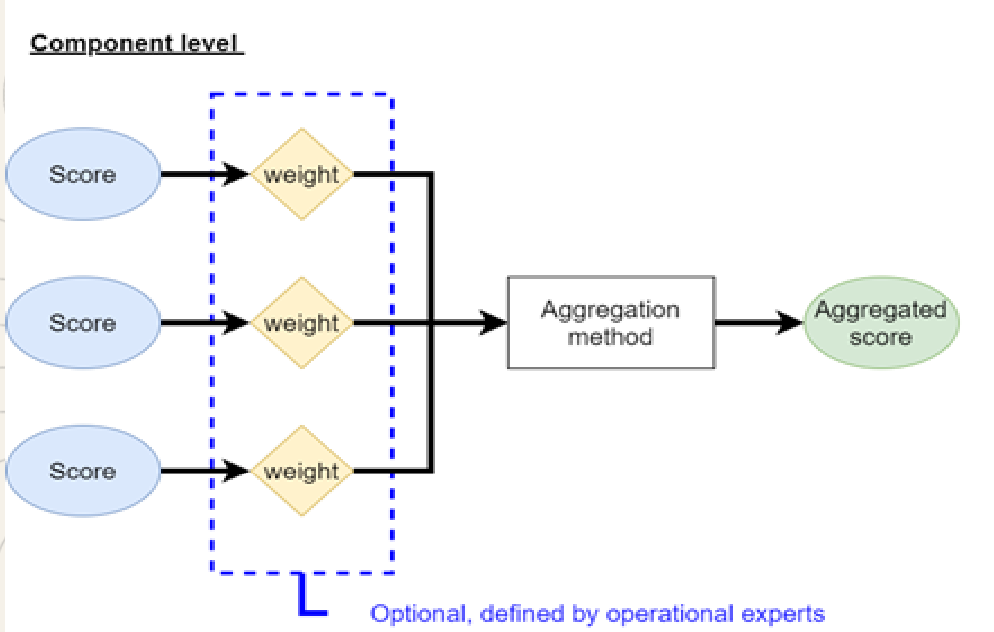


# DTI performance assessment

- 2022: >500 commercial C-UAS systems
- Different systems <> different use case scenarios
- Performance claims often unsupported by evidence
- Different test methodologies make comparison impossible
- No Silver Bullet
- Each operational environment will require different cUAS Detection Tracking and Identification capabilities

# DTI performance assessment

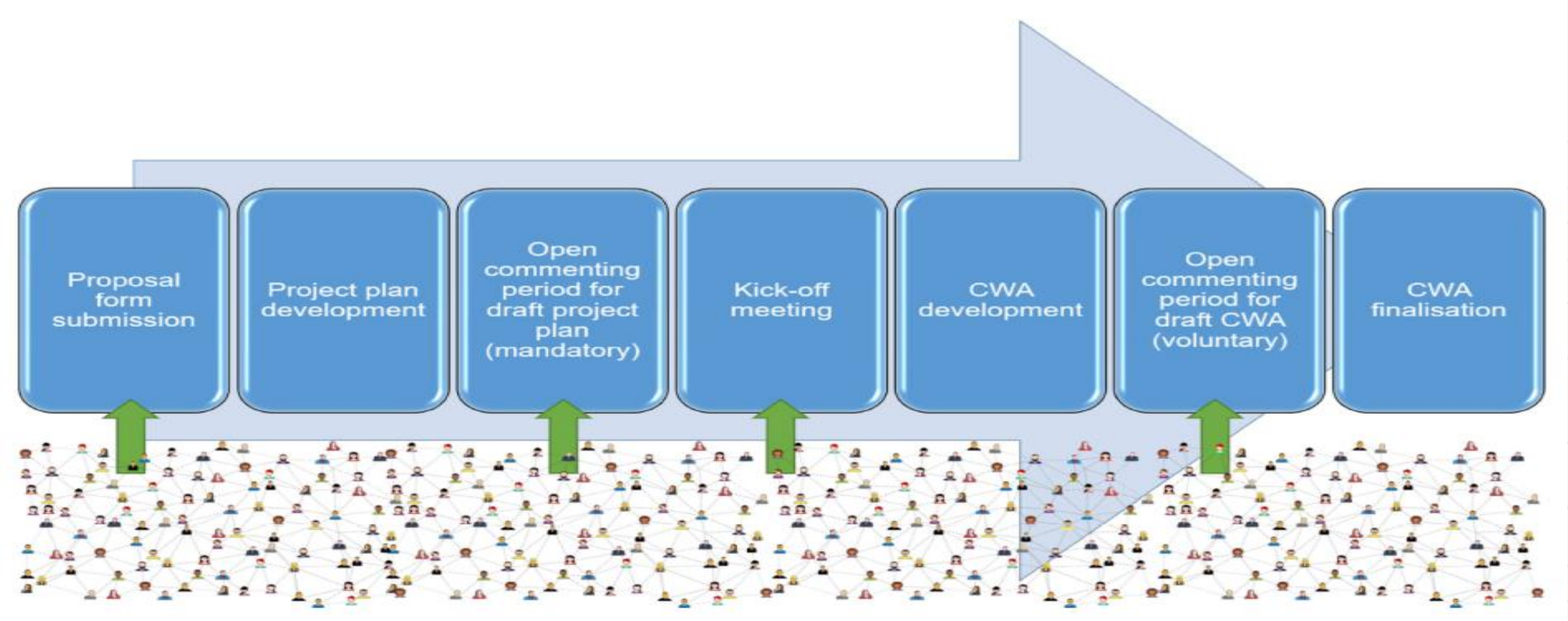
- NOT about ranking systems
- Technology-agnostic (= future-proof) method
- Standard, relevant, user-defined test scenarios
- Black-box validation approach
- Field validation & iterative design improvement
- Ability to test sub-system AND integrated functionalities (detection, tracking, identification)
- Start with user-defined test scenarios
- Derive metrics from the DTI output
- Generate 'score' per DTI functionality
- Optionally weigh the scores ➔ Total score



# DTI performance assessment

- Aim is to arrive at a pre-standard (CENELEC Workshop Agreement - CWA) by ~September 2024

- This is a (free) public process, register here if you're interested: https://www.cencenelec.eu/news-and-events/news/2023/workshop/2023-06-20-courageous/



# Neutralisation: High-Power Laser

- **Description**: High-power lasers are directed energy weapons designed to neutralize drones by focusing intense light beams on the target. The laser energy heats and damages critical components, such as the drone's electronics or structural elements, causing it to fail and crash.
- **Advantages**:
    - Precision targeting with minimal collateral damage.
    - Capability to engage multiple targets rapidly.
- **Challenges**:
    - High energy consumption and power requirements.
    - Limited effectiveness in adverse weather conditions (fog, rain, dust).
- **Example**: The U.S. military has developed systems like the High-Energy Laser Mobile Demonstrator (HEL-MD), capable of shooting down drones and other threats

# Neutralisation: RF Jamming & RF Spoofing

- **Description**: RF jamming involves emitting radio frequency signals to disrupt the communication between a drone and its operator, effectively causing the drone to lose control or return to its base. RF spoofing or hacking takes this a step further by sending deceptive signals to take control of the drone or mislead its navigation systems.
- **Advantages**:
  - Non-destructive method to neutralize drones.
  - Can be implemented over a wide area.
- **Challenges**:
  - Risk of interfering with other communication systems.
  - Advanced drones may have anti-jamming capabilities.


- **Example**: The DroneDefender by Battelle is a handheld device that uses RF jamming to disable drones within a certain radius

# Neutralisation: GNSS Jamming & Spoofing

- **Description**: GNSS jamming involves blocking the satellite signals that drones use for navigation, causing them to lose their positional awareness. GNSS spoofing involves sending false satellite signals to mislead the drone's navigation system, making it follow incorrect coordinates.
- **Advantages**:
  - Effective against drones relying heavily on GPS for navigation.
  - Can mislead drones without immediate destruction.
- **Challenges**:
  - GNSS spoofing requires precise timing and knowledge of satellite signals.
  - Possible disruption to civilian GNSS services.
- **Example**: Russian military forces have been reported to use GNSS jamming and spoofing extensively in conflict zones to protect against drone threats

# Neutralisation: Anti-Drone Drone (Interceptor)

- **Description**: These are specialized drones designed to intercept and neutralize hostile drones. They can engage targets through physical means, such as deploying nets, ramming, or using onboard kinetic weapons.
- **Advantages**:
  - High maneuverability and flexibility in targeting drones.
  - Reusable and capable of engaging multiple targets.
- **Challenges**:
  - Requires precise piloting or advanced autonomous systems.
  - Potential for collateral damage if the interceptor misses or crashes.
- **Example**: The Fortem DroneHunter is an interceptor drone that uses AI to autonomously detect, chase, and capture hostile drones with a net

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# Neutralisation: High-Power Microwave (HPM)

- **Description**: HPM systems emit powerful microwave bursts designed to fry the electronics of drones, effectively disabling their control systems and rendering them inoperable.
- **Advantages**:
  - Can disable multiple drones simultaneously within a broad area.
  - Non-lethal and does not rely on physical projectiles.
- **Challenges**:
  - High energy requirements & potential interference with friendly electronics.
  - Line-of-sight limitations & reduced effectiveness in cluttered environments.


- **Example**: The U.S. Air Force's THOR (Tactical High-Power Operational Responder) is an HPM system developed to counter swarms of drones

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# Neutralisation: Kinetic Interception

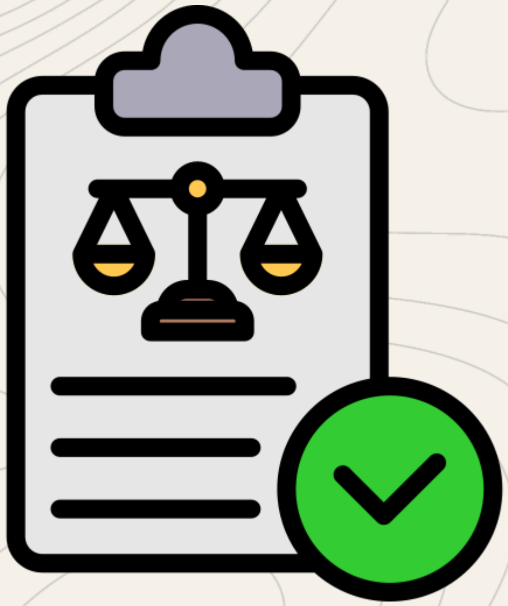
- **Description**: This method involves using physical projectiles or systems to shoot down drones. Kinetic interceptors can include anti-aircraft guns, missiles, or even small arms fire.
- **Advantages**:
  - Direct and immediate neutralization of drones.
  - Proven technology with established use in military applications.
- **Challenges**:
  - Risk of collateral damage from falling debris.
  - Requires accurate targeting systems and can be costly per engagement.
- **Example**: The C-RAM (Counter Rocket, Artillery, and Mortar) system, originally designed to intercept incoming projectiles, has been adapted to target drones using rapid-fire guns

# Future Trends and Innovations: Counter-drone

- Regulatory and ethical framework
- Predictive Analytics
- DTI
  - Behavioral Analysis
  - UTM Integration
  - More multi-sensor systems with more embedded AI
  - Man-Portable Systems and Vehicle-Mounted Systems
  - Formal performance assessment (COURAGEOUS)
- Response
  - Automated Response Systems
  - Directed Signal Jamming and Spoofing
  - Hacking & takeover
  - Directed Energy Weapons (HPM, Laser)
  - Interceptor systems

- The EU, under its CSDP, emphasizes the use of drones within the bounds of international law, promoting ethical usage that aligns with humanitarian laws. Member states are also influenced by NATO's policies, which standardize UAV operations among allied forces.

- As drone technology evolves, there is a need to update policies to address new capabilities like **AI** and **autonomous systems**. This includes revising **rules of engagement**, enhancing data protection measures, and developing frameworks for counter-drone technologies.



# Impact on Strategies and Doctrines

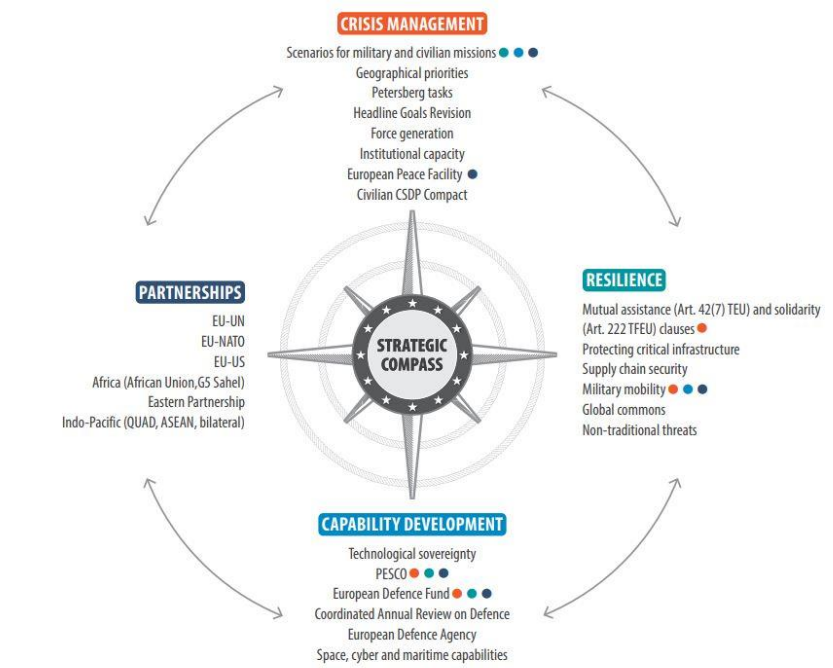
- Traditional doctrines are being revised to include UAV tactics, emphasizing rapid deployment, real-time intelligence, and precision targeting. Training programs are being updated to prepare personnel for drone operations, ensuring they can effectively utilize these assets in various scenarios.

- Developing comprehensive doctrines specific to drone warfare helps in **standardizing operational procedures**, ensuring consistent and effective use of UAVs across different branches of the military.

# Long-Term Planning and Investment

- Continuous investment in advanced technologies such as AI, machine learning, and autonomous operations is essential to keep up with technological advancements and emerging threats. However, **military acquisition cycles also need to be adapted, as they currently cannot keep up with the speed of innovation**

- Developing scalable drone programs allows for flexible responses to different threat levels and operational requirements, ensuring readiness for both small-scale and large-scale engagements.



# Long-Term Planning and Investment

- Prioritizing R&D initiatives helps maintain technological superiority and adaptability. Collaborative efforts with academic institutions and the private sector can drive innovation and accelerate the development of cutting-edge drone technologies.

- Engaging in partnerships with other nations and international organizations facilitates knowledge sharing, joint development projects, and coordinated efforts in addressing common security challenges. Participating in joint exercises also enhances interoperability and operational effectiveness among allied forces.

- Drones have an important **dual use** aspect, so there are important synergies to be sought with civil security actors

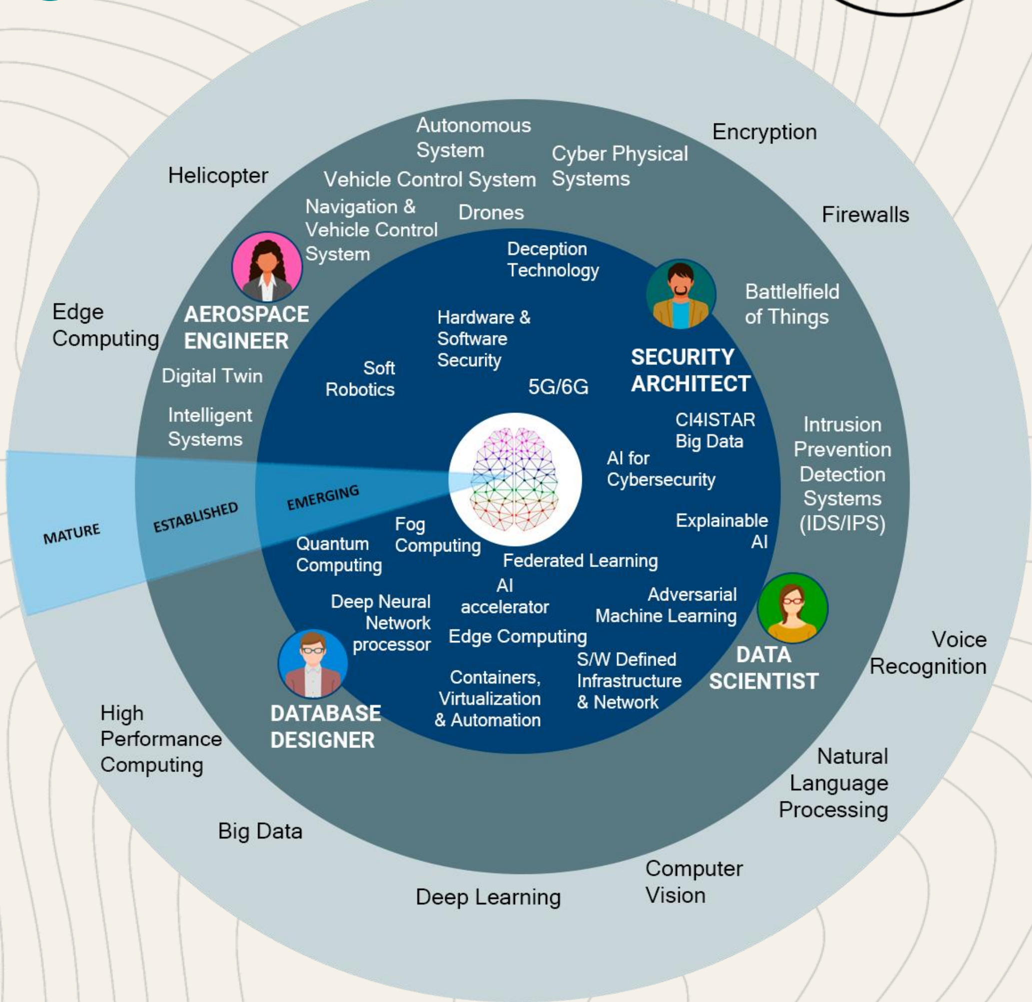
# Training the future generations

Alliance for Strategic Skills addressing Emerging Technologies in Defence: ASSETs+

ASSETs+ is an Erasmus+ project, aiming to close the gap between skills developed in universities and requirements on the terrain

30 partners from 8 countries and a broad ecosystem of stakeholders.

[https://assets-plus.eu/](https://assets-plus.eu/)



# Discussion & Conclusion

- Open Floor for Questions
- Discussion on Future Prospects
- Exchange of Ideas and Experiences

ROBOTICS & AUTONOMOUS SYSTEMS

DEFENCE

# Thank you!

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