



From Single Platform to Swarm: Operational Deployment of a Cooperative UAV–UGV System on the Digitised Battlefield

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ROJ



MINISTRY OF THE INTERIOR
OF THE CZECH REPUBLIC





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Motivation

COP, MDMP and the limits of single-platform ISR

2

Swarm in the C2 process

MDMP phases and information flow

3

ROJ system architecture

10 UAVs, 3 UGVs, onboard AI, communication

4

Multi-UAV trajectory planning

MDVRP and adaptive ant colony optimisation

5

Field validation

Tactical scenario in a military training area

6

Lessons learned & future work

Tactical implications, ROJ II



ROJ – An Artificial Intelligence-Controlled Robotic System for Intelligence and Reconnaissance Operations

Brno University of Technology

Faculty of Electrical Engineering and Communication

University of Defence

Faculty of Military Technology, Faculty of Military Leadership

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Follow-up: ROJ II (OZ01020024), Ministry of Defence – PRODEF





Motivation: Faster ISR for the Commander



Commanders need a real-time **Common Operational Picture (COP)**. Accelerating information gathering in the **MDMP** translates directly into tactical advantage.

Conventional ISR – single platform

- Limited spatial coverage
- Single point of failure
- One sensor at a time
- One dedicated operator per platform



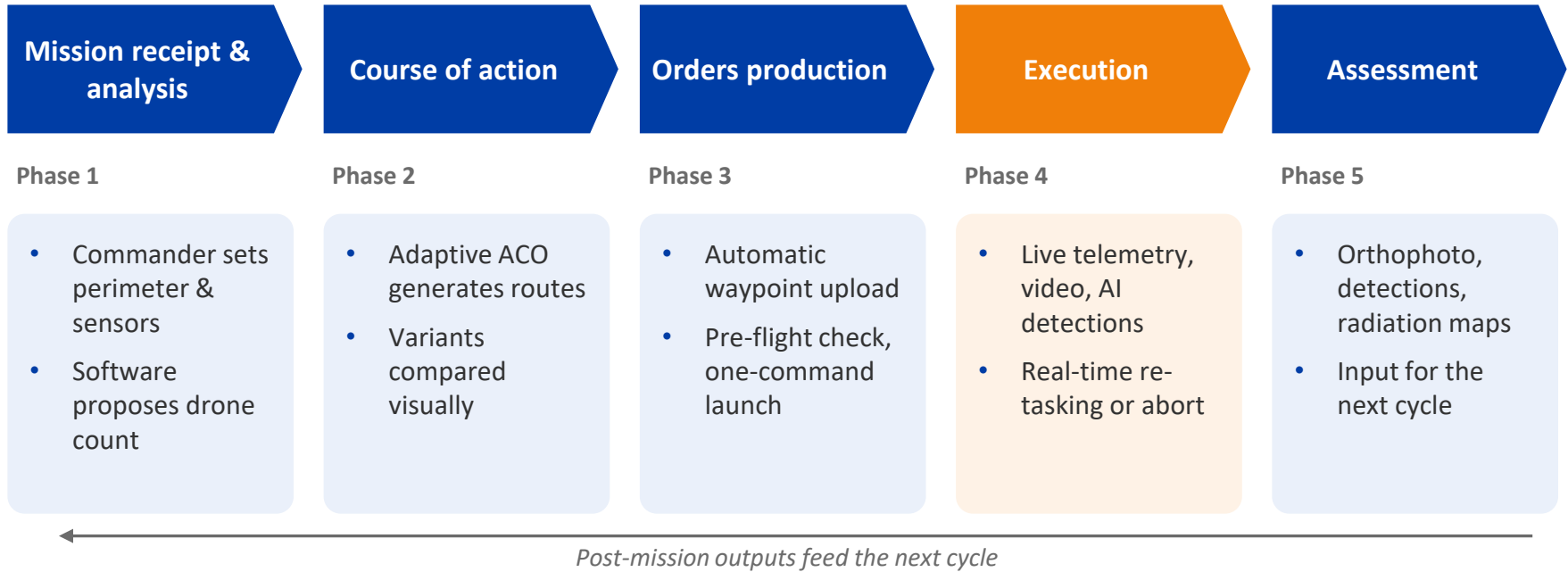
Swarm paradigm – UAV + UGV

- Large area covered in parallel
- Resilience through redundancy
- Diverse sensors, fused picture
- Commander-level mission control

Gap addressed: DARPA OFFSET, Perdix, KITU 2 and others explored swarm tactics, but none fielded an **air-ground swarm with onboard AI detection integrated into a national C2 system** in a realistic field scenario.



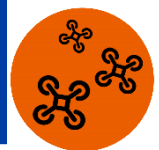
The Swarm in the Military Decision Making Process



Bidirectional link: the swarm remains a tool under the commander's authority – not an autonomous agent.



Information Flow: From Sensor to Commander



1 Onboard sensing & AI

RGB/IR, multispectral, radiation; YOLOv11 on each drone (ROS 2)



2 Data transmission

Custom UDP protocol over Wi-Fi 6, RFD 868 MHz backup, MANET-ready



3 Command software fusion

FastAPI + GraphQL + PostgreSQL; unified map-based picture



4 C2 integration

Detections exported to the ACR Battlefield Command Information System (BVIS)



Command software: planned trajectories, live positions, telemetry and video of all assets



ROJ System: 10 UAVs, 3 UGVs and a Control Station



10 DRONES



3 GROUND ROBOTS



CONTROL STATION

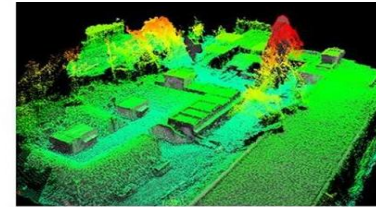
RGB camera



Thermal camera



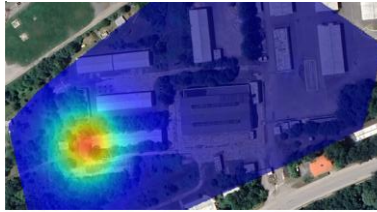
Laser scanning



Multispectral camera



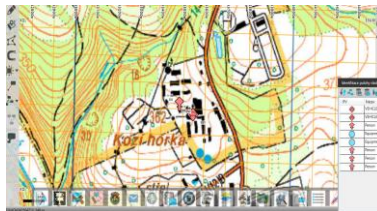
CBRN mapping



Data relay



BVIS compatibility





Swarm Composition and Operational Roles



ID	Designation	Platform	Operational role	Key sensor
1–7	Delta I–VII	T-DRONES M690PRO	Recon., detection, photogrammetry, CBRN, multispectral, relay	SIYI A8/ZR10/ZT6, SCIONIX
8	Falcon I	T-DRONES MX860	UGV aerial transport	SIYI A8
9	Falcon II	T-DRONES MX860	RGB/IR reconnaissance, cargo transport	Workswell Wiris Pro
10	Ares	Tarot X4	Cargo transport	SIYI A8
–	Orpheus XR	Wheeled UGV	Ground recon., CBRN identification	LiDAR, NaI(Tl)
–	Scout-mini	Compact UGV	Confined-space reconnaissance	–
–	Hermes-micro	Micro UGV	Aerial-deployed inspection	–



Delta (45 min, 1 kg)



Falcon (up to 9 kg)



Ares



Orpheus XR



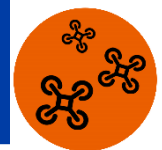
Scout-mini



Hermes-micro



Onboard AI Processing and Communication



YOLOv11n

nano model, 2.6 M parameters

~5 Hz

CPU inference at 960 px, ~70 % load

2,650

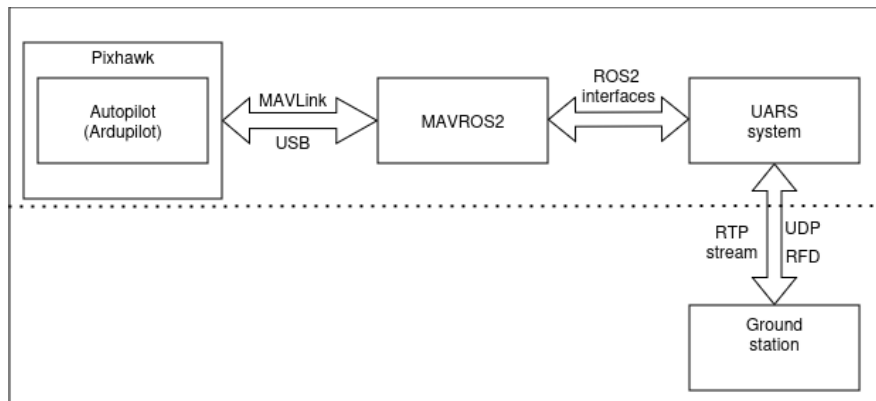
annotated aerial images of military equipment (with ACR)

4 classes

armoured vehicles, trucks, other vehicles, persons

Decentralised processing: detection runs on each drone (ASUS NUC, Intel Core i7, ROS 2 Humble). Lower latency and bandwidth; detections are buffered if the link drops.

Training: pre-training on VisDrone, fine-tuning on the military dataset.

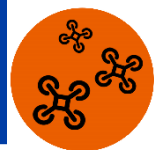


Communication & CBRN

- **Wi-Fi 6:** ~800 m (2.4 GHz), ~1 km (5 GHz)
- **RFD 868 MHz:** backup telemetry up to 3.5 km
- **MANET MPU5:** ready for operational deployment
- **CBRN:** 2× EJ-200 on UAVs, NaI(Tl) on Orpheus

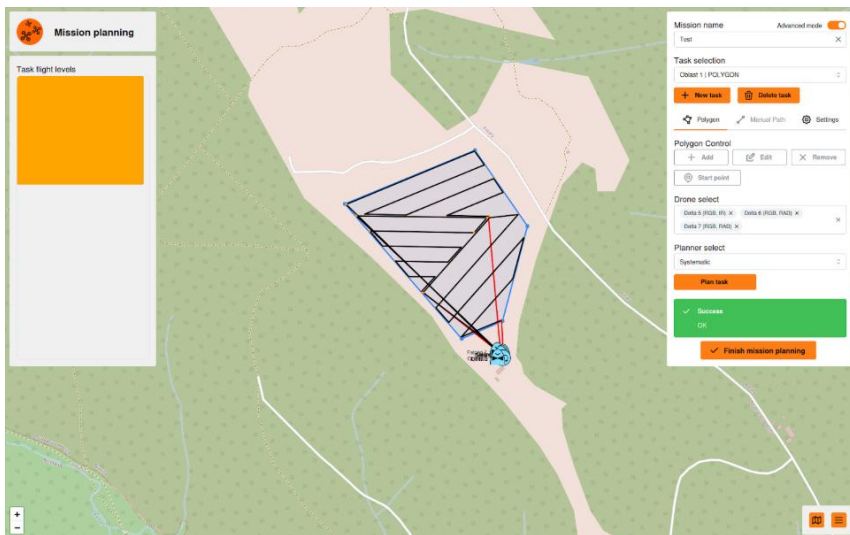


Trajectory Planning for Multi-UAV Reconnaissance



Problem: Multi-Depot Vehicle Routing Problem (MDVRP) – each UAV starts and returns to its own take-off point under flight-time and payload constraints; NP-complete.

Solution: adaptive Ant Colony Optimisation with node clustering (IEEE TEVC 2023), C++ library in the command software.



Systematic planner – photogrammetric coverage



Metaheuristic (ACO) planner – reconnaissance routes

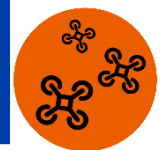
Open-terrain model

Urban model (line-of-sight, building perimeters)

Beginner / advanced mode



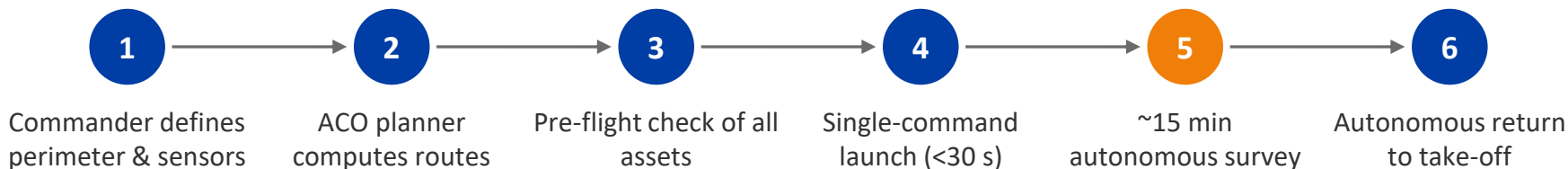
Field Validation: Tactical Scenario



- **Date & place:** 11 September 2025, military training area
- **Area:** defended area, perimeter of ~30 ha
- **Targets:** 2× BVP-2 IFV, 2× Tatra trucks, 2× Toyota Hilux + soldiers on varied backgrounds
- **Evaluators:** ACR application guarantor, Fire Rescue Service
- **Criteria:** detection, mission time, map quality, C2 integration

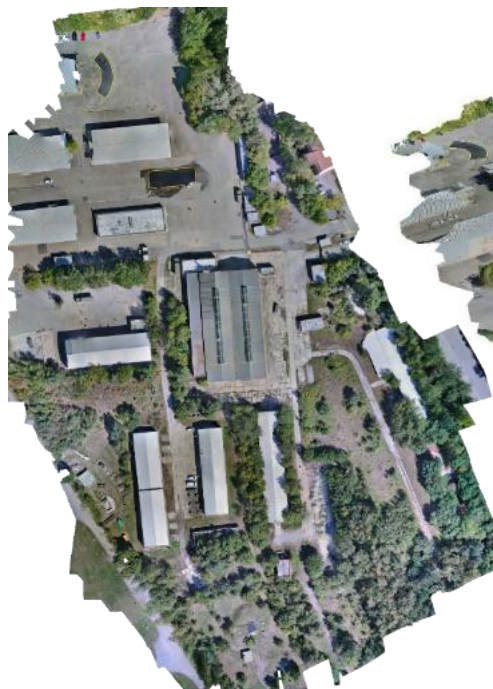
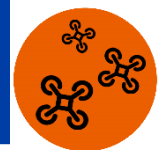


Swarm prepared for simultaneous take-off





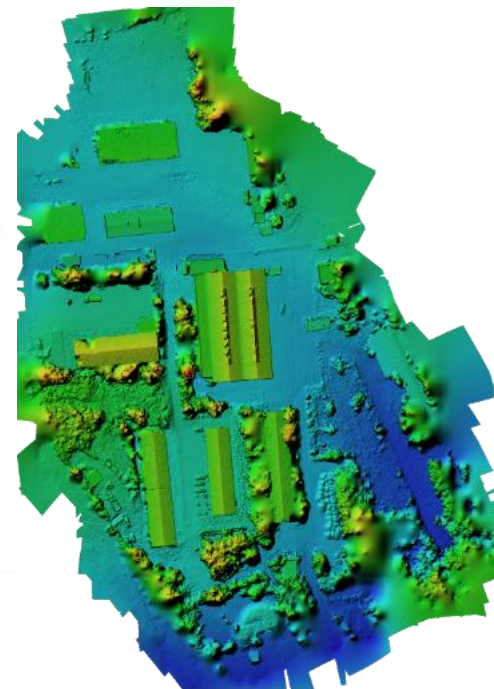
Field Results: Photogrammetric Outputs



Orthophoto



Textured 3D model

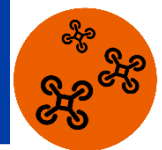


Digital elevation model

Simultaneous multi-drone photogrammetry: orthophoto with 5 cm GSD (363 MB), Agisoft Metashape with multi-camera calibration



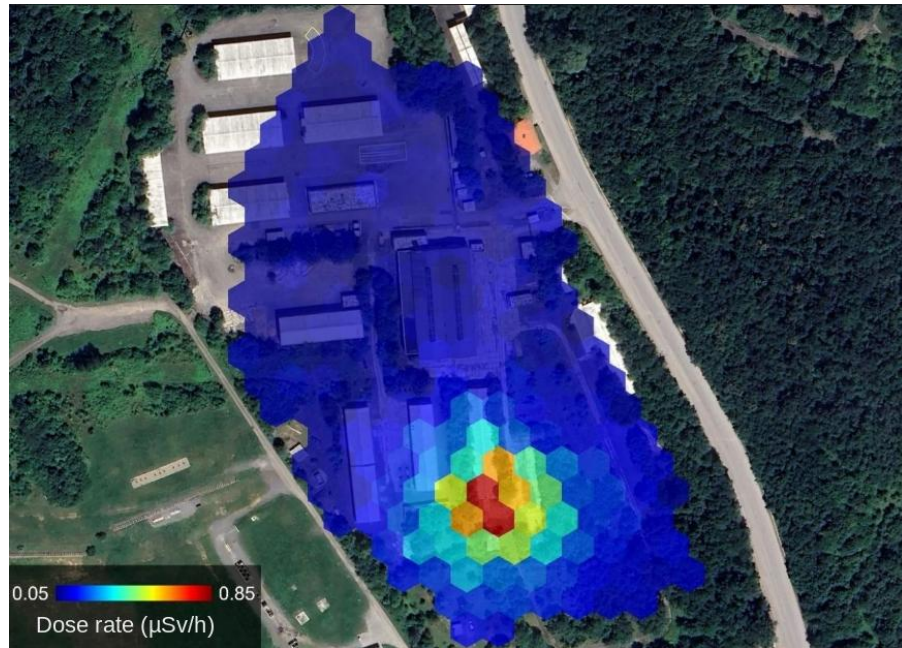
Field Results: Onboard Object Detection



All 6 vehicles detected (100 % recall for vehicle classes). Each detection is sent to the command software with class label, confidence, thumbnail and geographic coordinates computed from drone position and gimbal orientation.



Field Results: Radiation Monitoring (CBRN)



UAV gamma dose-rate map (EJ-200 scintillators)

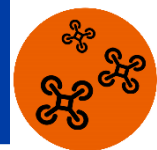


Ground robot route for close-range inspection

Air-ground cooperation: drones rapidly localise elevated radiation from altitude, then the Orpheus UGV performs NaI(Tl) spectrometry to identify the radionuclide.



Key Results of the Demonstration



100 %

**recall on vehicle
targets**

6/6 vehicles detected

30 ha

covered in ~15 min

single drone: est. 2–3 h

5 cm

GSD orthophoto map

multi-drone
photogrammetry

BVIS

**detections exported to
national C2**

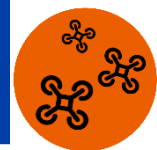
first such swarm
integration

Limitations observed

- Camouflaged personnel were not detected – camera resolution at 20–30 m altitude and effective camouflage material.
- The detection dataset is specific to the equipment types and terrain of the training area – broader training data needed.



Tactical Implications and Lessons Learned



New capabilities

Temporal compression

Faster OODA loop – minutes instead of hours

Multi-sensor COP

RGB/IR detections, map and UGV data in one mission

Air–ground synergy

UAVs survey wide areas, UGV inspects up close

Reduced risk to personnel

No human scouts in the contested area

Challenges → next steps

Communication range

Wi-Fi 6 ~1 km → MANET integration

Camouflaged targets

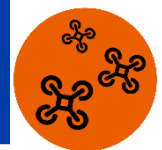
Thermal + multispectral fusion

EW vulnerability

GNSS jamming and link disruption

Energy autonomy

~55 min per sortie → relays, battery swap



Conclusions

- ✓ A heterogeneous swarm of 10 UAVs and 3 UGVs was integrated into the MDMP and the national C2 chain.
- ✓ Field validation: 30 ha in 15 min, all vehicles detected, 5 cm orthophoto, export to BVIS.
- ✓ Cooperative swarms are ready to move from research into existing military operational frameworks.

ROJ II (OZ01020024, MoD – PRODEF)

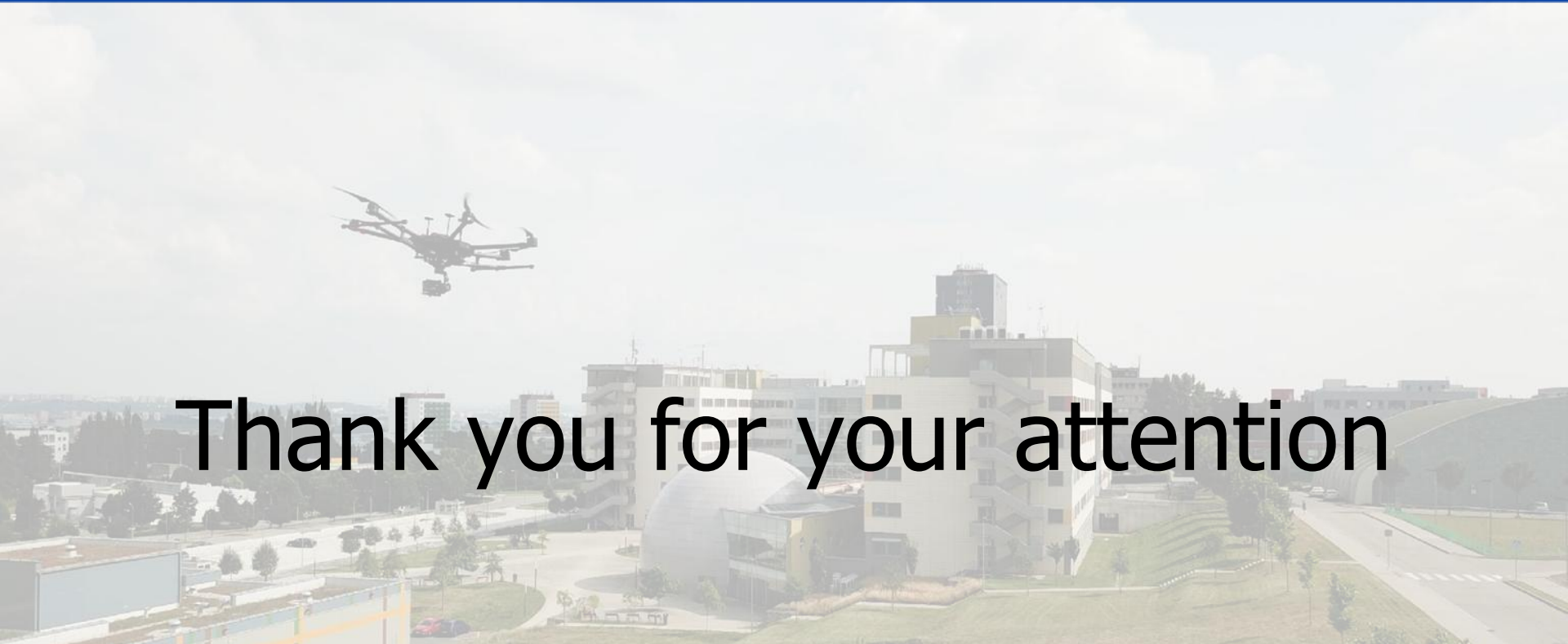
Autonomous operation in electromagnetically contested environments: GNSS jamming/spoofing, autonomous CBRN detection.

SAFEGROUND (Horizon Europe)

HORIZON-CL3-2025-01-FCT-04 – swarm platforms with mine-detection sensors for humanitarian demining.

ACR exercises

Deploying ROJ outputs at exercises; broader dataset and sensor fusion for camouflaged targets.



Thank you for your attention

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