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

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ROJ

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Outline

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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

Mission receipt & analysis	Course of action	Orders production	Execution	Assessment
Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
• Commander sets perimeter & sensors • Software proposes drone count	• Adaptive ACO generates routes • Variants compared visually	• Automatic waypoint upload • Pre-flight check, one-command launch	• Live telemetry, video, AI detections • Real-time re-tasking or abort	• Orthophoto, detections, radiation maps • Input for the next cycle

Post-mission outputs feed the next cycle

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

RGB camera

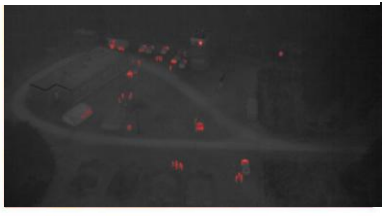


Multispectral camera

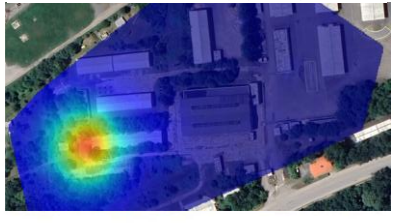


3 GROUND ROBOTS

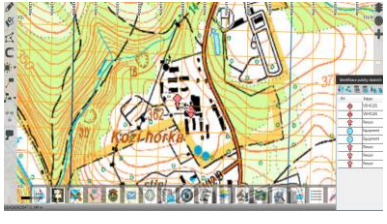
Thermal camera



CBRN mapping

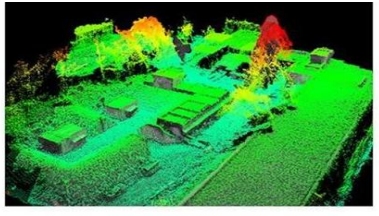


BVIS compatibility



CONTROL STATION

Laser scanning



Data relay



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

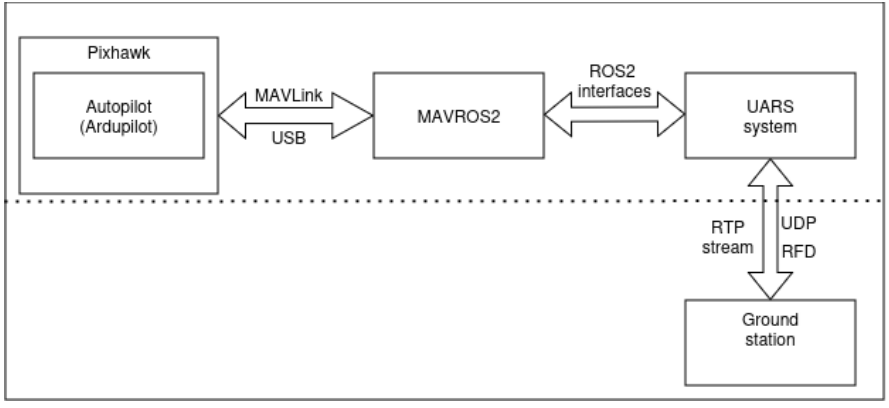
~5 Hz
CPU inference at 960 px, ~70 % load

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.



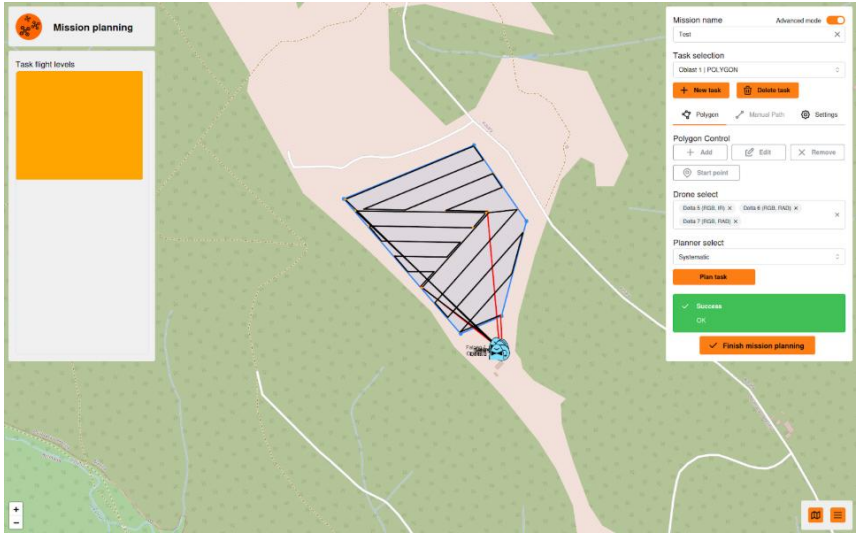
Communication & CBRN

- **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



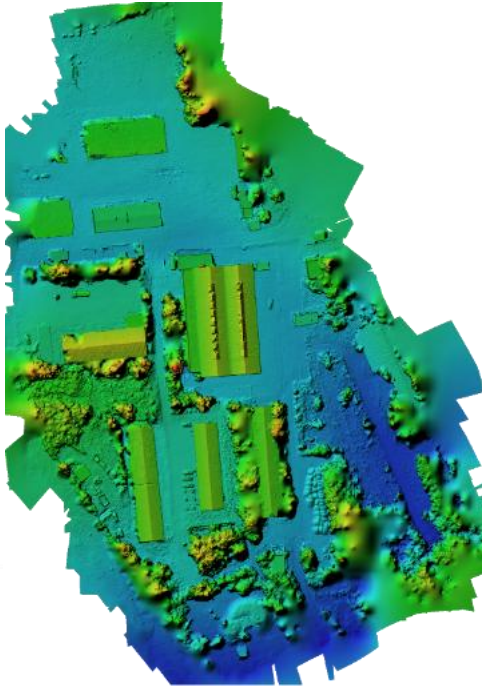
Swarm prepared for simultaneous take-off

1. Commander defines perimeter & sensors
2. ACO planner computes routes
3. Pre-flight check of all assets
4. Single-command launch (<30 s)
5. ~15 min autonomous survey
6. Autonomous return to 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

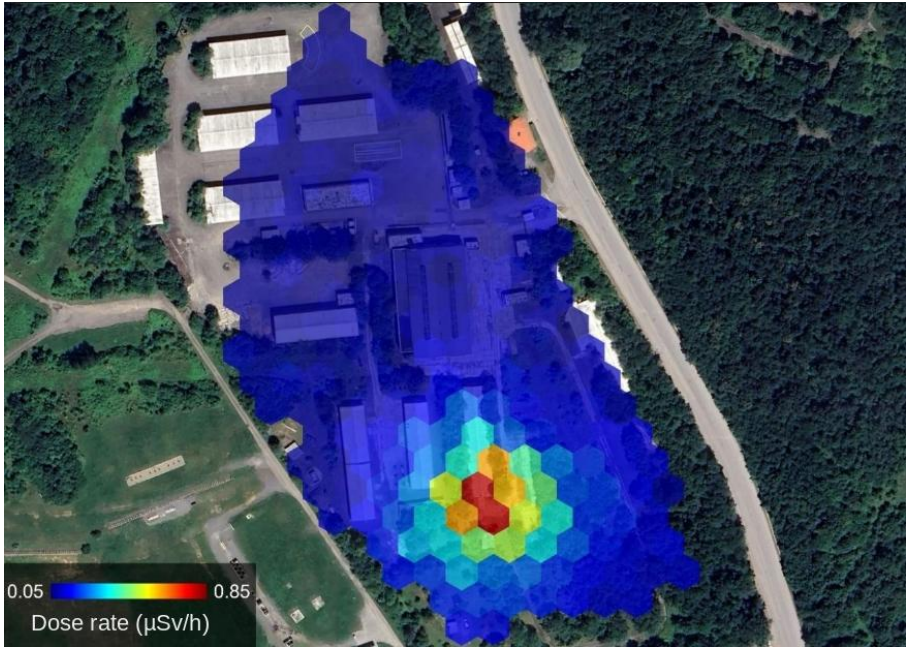




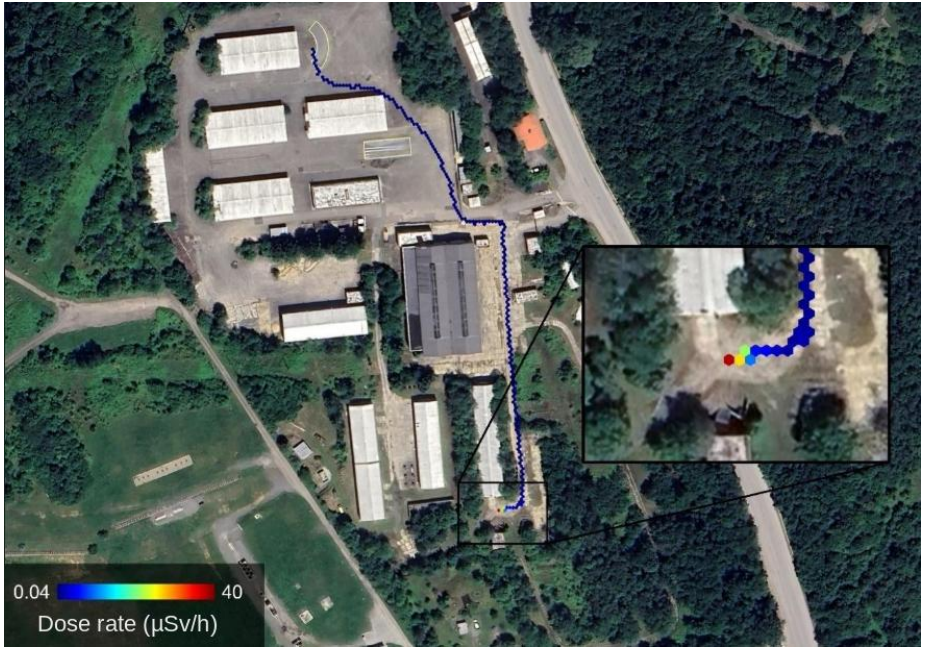


All 6 vehicles detected (100 % recall for vehicle classes). Each detection is sent to the command software with class label, confidence, thumbnail and geographic coordinates computed from drone position and gimbal orientation.

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 and Future Directions

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.

Acknowledgement



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