Drones
2026

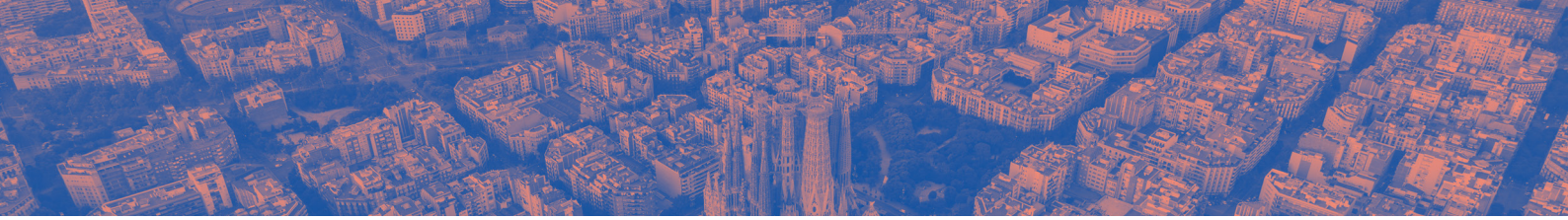
Conference

Drones 2026: Mapping the Knowledge

11–13 November 2026, Barcelona, Spain



Program and Abstract Book



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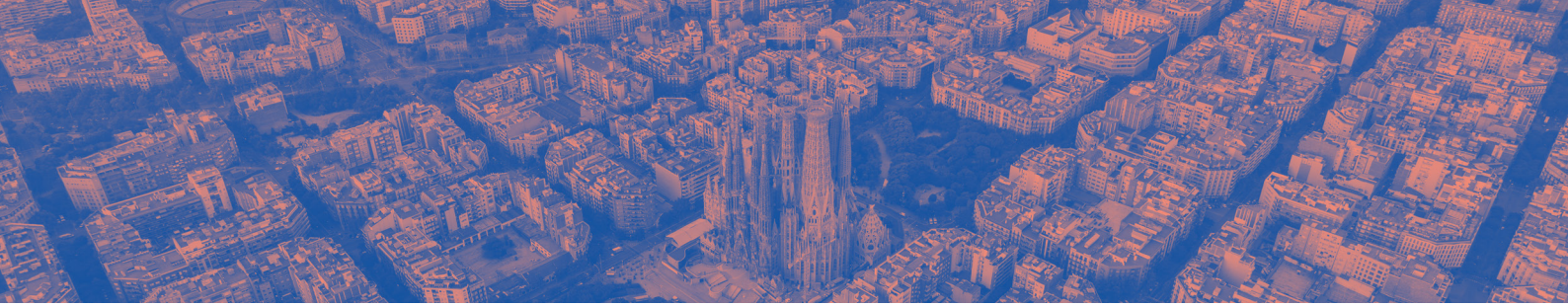
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Welcome from the Chairs

Dear Colleagues,

We are pleased to welcome you to **Drones 2026: Mapping the Knowledge**, which will take place in Barcelona, Spain, from 11 to 13 November 2026. This conference aims to bring together researchers, industry professionals, and experts from around the world to share the latest advancements, exchange ideas, and foster collaborations in the field of the design, development, and application of drone technologies.

Over the course of three days, we will explore a wide range of novel and attractive topics distributed through different thematic sessions, including keynote lectures, oral presentations, and poster sessions. Our program is designed to provide engaging networking for discussing cutting-edge research, emerging challenges, and future directions in the field.

We encourage you to actively participate by presenting your work, engaging in discussions, and networking with fellow attendees. Beyond the scientific sessions, Barcelona offers a vibrant setting to connect with colleagues while enjoying its rich culture, history, and cuisine.

We look forward to an inspiring and productive conference and to welcoming you to Drones 2026: Mapping the Knowledge!

Sincerely,

Prof. Dr. Diego González-Aguilera
Prof. Dr. Pablo Rodríguez-Gonzálvez

Event Chairs



Prof. Dr. Diego González-Aguilera
Universidad de Salamanca, Spain



Prof. Dr. Pablo Rodríguez-Gonzálvez
Universidad de León, Spain

Keynote Speakers



Dr. Dimitris Perikleous
ACCELIGENCE, Cyprus



Mr. Marc Beltran
EU Drone Port, Spain



Ms. Beatriz Rodríguez Romero
Advanced Center for Aerospace Technologies

Invited Speakers



Prof. Dr. Carlos Miguel Tavares Calafate
Universidad Politécnica de Valencia (UPV), Spain



Dr. Ricardo Díaz-Delgado
Spanish Space Agency / Agencia Espacial Española (AEE), Spain



Prof. Dr. Francesco Nex
Earth Observation Science (EOS) Department, University of Twente, the Netherlands



Prof. Dr. Fabio Remondino
Bruno Kessler Foundation, Italy



Prof. Dr. Belén Riveiro Rodríguez
Universidad de Vigo, Spain

Scientific Committee



Dr. Margarita Mulero-Pázmány
Department of Animal Biology, University of Malaga, Spain



Prof. Dr. Abdessattar Abdelkefi
Department of Mechanical and Aerospace Engineering, New Mexico State University, USA



Dr. Emmanouel T. Michailidis
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Prof. Dr. David R. Green
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Prof. Dr. Bo Li
School of Electronics and Information, Northwestern Polytechnical University, China



Prof. Dr. Eben N. Broadbent
School of Forest, Fisheries, and Geomatics Sciences, University of Florida, USA



Prof. Dr. Joaquín Martínez Sánchez
Department of Natural Resources and Environmental Engineering, School of Mining and Energy Engineering, Universidad de Vigo, Spain



Prof. Dr. Petros S. Bithas
Department of Digital Industry Technologies, National and Kapodistrian University of Athens, Greece



Dr. Haibin Duan
School of Automation Science and Electrical Engineering, Beihang University, China



Prof. Dr. Kimon P. Valavanis
Department of Electrical and Computer Engineering, University of Denver, USA



Prof. Dr. Farzaneh Dadrass Javan
Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands

Drones 2026:
Mapping the Knowledge

Wednesday, 11 November 2026

CEST	Session
From 12:00	**Check-in**
13:00–13:15	**Opening Ceremony**
13:15–14:00	**Keynote Speaker - Dimitris Perikleous**
14:00–15:00	**S1 & S2. Drone Design, Development, and Communications (Part 1)** Selected Presentations
15:00–15:45	**Coffee Break**
15:45–16:30	**S1 & S2. Drone Design, Development, and Communications (Part 2)** Invited Speaker - Carlos Tavares Calafate Selected Presentations
16:30–17:30	**S4. Artificial Intelligence Applications for Drones (Part 1)** Invited Speaker - Fabio Remondino Selected Presentations

Drones 2026:
Mapping the Knowledge

Thursday, 12 November 2026

CEST	Session
9:00–9:45	**Keynote Speaker - Marc Beltran**
9:45–10:30	**S4. Artificial Intelligence Applications for Drones (Part 2)** Selected Presentations
10:30–11:00	Coffee Break
11:00–11:45	**S4. Artificial Intelligence Applications for Drones (Part 3)** Selected Presentations
11:45–12:15	**S5. Drones in Rangelands, Agriculture, and Forestry (Part 1)** Selected Presentations
12:15–12:30	Group Photo
12:30–14:00	Lunch Break & Poster Session A
14:00–15:30	**S5. Drones in Rangelands, Agriculture, and Forestry (Part 2)** Invited Speaker – Ricardo Díaz-Delgado Selected Presentations
15:30–16:00	Coffee Break & Poster Session A
16:00–17:30	**S7. Drones in Geospatial Industry** Invited Speaker – Francesco Nex Selected Presentations
at 20:00	Conference Dinner Location: 7 Portes Restaurant (Pg. d'Isabel II, 14, Ciutat Vella, 08003 Barcelona)

Drones 2026:
Mapping the Knowledge

Friday, 13 November 2026

CEST	Session
08:15–09:00	**Keynote Speaker - Beatriz Rodríguez Romero**
09:00–10:45	**S6. Drones in Security and Defense** Selected Presentations
10:15–10:45	**Coffee Break & Poster Session B**
10:45–12:15	**S8. Emerging Applications of Drones** Selected Presentations Invited Speaker – Belén Riveiro Rodríguez
12:15–13:45	**Lunch Break & Poster Session B**
13:45–14:45	**S3. Guidance, Navigation, and Control** Selected Presentations
14:45–15:00	**Closing & Awards Ceremony**

General Information

Drones 2026: Mapping the Knowledge will be held in Barcelona, Spain, from 11 to 13 November 2026. This conference aims to bring together researchers, industry professionals, and experts from around the world to share the latest advancements, exchange ideas, and foster collaborations in the field of design, development, and application of drone technologies.

Conference Venue

Casa Convalescència
C/ de St. Antoni Maria Claret, 171, Barcelona, Spain

Registration Desk

The desk for registration, information and distribution of documents will open from 12:00h on 11 November 2026.

Certificate of Attendance

Participants of the event will be able to download an electronic Certificate of Attendance by accessing their dashboards on Sciforum.net once the event is concluded. The certificates will be found under the “My Certificates" section.

Disclaimer

Delegates will receive a name-badge at the Information Desk, upon registration. The badge must be worn prominently in order to gain access to the congress area during the event. Admission will be refused to anyone not in possession of an appropriate badge.

Insurance

The organizers do not accept liability for personal accidents, loss, or damage to private property incurred because of participation in Drones 2026: Mapping the Knowledge. Delegates are advised to arrange appropriate insurance to cover travel, cancellation costs, medical, and theft or damage of belongings.

The Venue

Casa Convalescència is located in a vibrant zone of the city, near the Sagrada Família, with easy access to urban and suburban areas of the city. It is part of the Sant Pau Art Nouveau Site. Designed by the architect Lluís Domènech i Montaner, it was built between 1905 and 1930. After housing the Hospital de la Santa Creu i Sant Pau (one of Europe's oldest healthcare centers) for more than eight decades, a restoration project commenced on the old pavilions in 2009. This process has restored the beauty of one of the iconic works of Catalonia's home-grown art nouveau, modernism.



Conference Dinner

We are excited to announce that the Conference Dinner Reception will be held at the prestigious **7 Portes**, one of Barcelona's most emblematic restaurants and renowned for its traditional Catalan and Mediterranean cuisine. Located between the Born and Barceloneta neighbourhoods and within walking distance of Barceloneta Beach, the restaurant offers a distinctive setting in which to experience Barcelona's culinary and cultural heritage.

- **Time:** Thursday, 12 November 2026, at 20:00 CET
- **Location:** 7 Portes Restaurant. Pg. d'Isabel II, 14, Ciutat Vella, 08003 Barcelona.

Join us for an enjoyable evening of good food, conversation, and networking in one of Barcelona's most historic dining venues!

Conference Secretariat



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Emergency Information

All emergencies in Barcelona: 112

Fire brigade: 080

Accident / Ambulance: 061

National Police: 091

Local Police: 092

Abstracts — Talks

Keynote and Invited Talks

Keynote Speaker

Designing Drones Around the Mission: From Requirements to Real-World Impact

Dimitris Perikleous

[1] *UAV Department, Acceligence Ltd., Nicosia, 1066, Cyprus*

A drone is only as useful as the answer it brings back. Yet in practice drones are often chosen first and given a mission afterwards, and the gap only shows up in the field. This keynote argues for the opposite: start from what the mission needs to deliver, turn those needs into clear, measurable requirements, and let them shape the aircraft. That means its configuration, size, payload and the way it flies.

The talk follows this idea through three situations that operators face in practice:

- **one mission** that demands a purpose-built aircraft;

- **many missions** served by a single multipurpose platform;

- **missions that change over time**, handled by an aircraft designed to be reconfigured.

Each case draws on systems that were designed, built and tested in real operating conditions, from geophysical surveying to emergency response. Together they show how a single requirement can drive the whole design, why flexibility is never free, and how to decide how much of it a mission really needs.

The talk then brings these lessons together in a simple map for choosing between dedicated, multipurpose and reconfigurable designs. It closes with the open challenges that still separate a working prototype from a reliable tool that people trust in their daily work..

Keynote Speaker

From Lab to Sky: Why Certification Is the Missing Link Between Drone Research and Real-World Impact

Marc Beltran

[1] *EU Drone Port, Spain*

Drone research has never moved faster. New airframes, autonomy stacks, detect-and-avoid systems and swarm architecture appear in the literature every month. Yet a large share of this innovation never leaves the test field. The barrier is rarely technical performance. More often, it is the lack of a credible, repeatable way to demonstrate that a system is safe enough to fly over people, beyond visual line of sight, or in shared airspace.

This keynote argues that certification is not a bureaucratic afterthought but the mechanism that converts research into deployable technology. Drawing on direct experience as a Notified Body under the European UAS framework (Regulations (EU) 2019/945 and 2019/947), the talk maps how product conformity, class marking, design verification and the SORA risk methodology connect laboratory results to operational approval. It shows where academic work already produces the evidence regulators need, and where it falls short: reliability data, failure-mode analysis, containment performance and software assurance.

Through real certification cases, the talk identifies the most common gaps between promising prototypes and approvable products, and how research groups can design for compliance from the start. It also looks ahead to the challenges that current frameworks are still learning to address: U-space integration, heavy-lift cargo platforms, dock-based autonomous operations and AI-driven flight control.

The central message is simple. Society will only accept drones at scale when it can trust them, and certification is how that trust is built. Researchers who understand this process can shorten the path from publication to impact by years.

Keynote Speaker

Software Development for Uncrewed Aerial Systems: From Drones to High-Altitude Platforms

Beatriz Rodríguez Romero

[1] *Perception and AI Unit, Advanced Center for Aerospace Technologies (CATEC), Seville, Spain*

Software is essential for the development and operation of uncrewed aerial systems. This work presents software solutions developed for ground control stations and onboard computers, focusing on sensor control, data collection, communication between systems and onboard data processing.

The work includes the development and testing of software that connects different system components and allows them to exchange data. It also addresses common challenges, such as ensuring reliable communication between ground and onboard systems and working with limited computing resources.

Drones provide a practical and accessible way to develop and test these software capabilities. They can help validate solutions before using them in more complex aerial platforms, such as High-Altitude Platform Systems (HAPS), where testing and integration can be more difficult and require more resources.

This work shows how software development and testing with drones can help improve system integration, communication and data processing, supporting the development of future high-altitude observation systems.

Invited Speaker

UAV Technologies: Challenges, Innovations, and Future Perspectives

Carlos T. Calafate

[1] *DISCA, Universitat Politècnica de València, Valencia, Spain*

Unmanned Aerial Vehicles (UAVs) are rapidly transforming a wide range of applications, including surveillance, precision agriculture, logistics, disaster management, environmental monitoring, and infrastructure inspection. Advances in autonomous systems, artificial intelligence (AI), wireless communications, and distributed computing are expanding UAV capabilities and enabling increasingly complex operations in dynamic and uncertain environments. However, the widespread deployment of UAVs raises important technological, operational, and security challenges that must be addressed to ensure their safe, reliable, and efficient integration into future networked environments.

This keynote explores the evolution of UAV autonomy, from remotely operated platforms to highly autonomous systems capable of independent navigation, mission planning, and decision-making. Particular attention is given to UAV swarms, where multiple drones collaborate through distributed intelligence, coordinated control, and cooperative task allocation to accomplish complex missions. The role of emerging communication technologies, including 5G/6G networks, device-to-device communications, and edge computing, is examined in the context of supporting low-latency connectivity, real-time coordination, and reliable information exchange among UAVs.

The keynote also addresses the challenges associated with integrating UAVs into urban environments, including airspace management, collision avoidance, infrastructure connectivity, and coexistence with other airspace users. Furthermore, it highlights the growing role of AI in autonomous navigation, environmental perception, intelligent decision-making, and adaptive mission execution. As UAV systems become increasingly interconnected, cybersecurity, privacy, data protection, and resilience against malicious attacks emerge as critical concerns for future UAV networks.

Invited Speaker

UAV in long-term ecological monitoring: contributing to baselines for ecosystem assessment and management

Ricardo Díaz-Delgado

[1] *Earth Observation, Spanish Space Agency, Sevilla, Spain*

Long-term ecological monitoring enable to build baselines for ecosystem dynamics and assess pressures from recurrent droughts, warming, and disturbance regimes. Over the past decade, Unmanned Aerial Systems (UAS) have transitioned from opportunistic observation tools into essential proximal remote sensing platforms, bridging the critical spatial and temporal gap between in situ field measurements and satellite Earth observation. This presentation reviews methodological advances and operational lessons learned from more than a decade of drone-based ecological monitoring in protected areas. Leveraging ultra-high-resolution multispectral. LiDaR and thermal sensors, we demonstrate feasible workflows for the monitoring of terrestrial and aquatic vegetation status, including phenology, disturbance effects and trends. Replicated and ad-hoc flight missions allow monitoring restoration actions, recovery after disturbance or identifying invasive species and algal blooms to inform practitioners and decision-making. By coupling UAV imagery with in situ data we are able to monitor mast seeding (i.e. acorn production), crown defoliation, and early-stage dieback symptoms less detectable by standard satellite pixels. Furthermore, multi-rotor and fixed-wing UAS payloads facilitate proximal mapping of topsoil moisture dynamics and canopy water stress at sub-decimetre scales, providing crucial insights into plant-soil-water interactions in semi-arid rangelands and post-fire regenerating shrublands. Additionally, UAS datasets serve as robust, spatially explicit ground-truth benchmarks for calibration, validation and upscaling to medium- and high-resolution satellite constellations. Harmonizing drone flight protocols, radiometric calibration routines, and data repositories is imperative to translate drone imagery into standardized Essential Ecosystem Variables and actionable management indicators. Drones are not only suitable for mapping, we can also use them to collect samples in a systematic way, or to autonomously fly below tree canopies. In summary, this keynote addresses the most frequent drone applications for long-term ecological monitoring of natural areas that can be used to measure and upscale in situ measurements to satellite images and highlights applications providing baseline for the management of forest health, drought resilience, and sustainable protected areas stewardship under global change.

Funding: The author wants to sincerely thank the Spanish National Parks Organism (OAPN) and CSIC for the funding of the monitoring program as well as to Consejería de Medio Ambiente of Junta de Andalucía. The Ministry of Science, Innovation and Universities also contributes to the long-term support of ICTS Doñana. I am also grateful to Doñana protected area management administration for its permanent assistance on field work and data sharing. eLTER Plus and PPP EU Horizon 2020 research projects funded some of the research.

Invited Speaker

From Sensors to Autonomy: UAV Innovations Reshaping the Geospatial Workflow

Francesco Nex

[1] *GeoInformatics Department, University of Twente/ITC Faculty, Enschede, The Netherlands*

Recent advances in drone hardware and software have transformed UAVs from remotely piloted data collectors into intelligent systems capable of operating in complex, unknown environments. Faster, lighter and more accurate sensors have driven remarkable gains in data quality, but the real revolution has come from AI-based algorithms that let drones navigate autonomously, process data on the spot, and deliver actionable information to end users in real time.

This presentation shows how 3D maps are no longer post-flight products but are built while the drone is still in the air: real-time bundle adjustment, zero-shot solutions for real-time mono and stereo reconstruction, and scene-graph construction turn image streams into accurate 3D models of outdoor and indoor spaces. In these approaches, however, mapping still depends on humans deciding where to fly. It is then shown how deep reinforcement learning enables autonomous exploration in contexts such as indoor search and rescue and wildfire detection and tracking, reconstructing 3D scenes without a human in the loop. Recent progress in large language models goes one step further, turning image streams into structured, human-readable scene knowledge. Ultimately, methods such as World Action Models and, more broadly, Generative AI — already proven in autonomous driving — could soon give geospatial drones the ability to understand and predict the world they map. Drones will not just capture data; they will reason about it. This is the next leap for the geospatial community.

Invited Speaker

Drones and AI to Support Conservation Ecology

Fabio Remondino

[1] *3D Optical Metrology Research Unit, Bruno Kessler Foundation, Italy*

TBA

Invited Speaker

Scaling Up the Structural Assessment of Ageing Bridges with UAVs

Belén Riveiro Rodríguez

[1] *CINTECX, University of Vigo, Vigo, 36316, Spain;*

The risk of bridge collapse is real and rising. Thousands of bridges in Europe and North America have outlived the loads, traffic and climate they were designed for, and most of them are never monitored. Over the past decade, geomatics has given structural engineers new tools to assess these structures: laser scanning and photogrammetry produce point clouds that can be segmented automatically into structural members, converted into BIM and finite-element models, and calibrated with vibration tests. Yet inaccessible structures still escape us. Even after dense terrestrial and mobile scanning campaigns, inner members, joints and under-deck areas remain hidden, and the geometry is rarely reliable enough to drive a structural model. To understand how a damaged steel truss bridge really behaves, we had to take it to the laboratory, where a full-scale test revealed latent resistance mechanisms that no field survey could have captured, and where hundreds of simulated damage scenarios trained AI models for damage detection and early warning. The methods exist; what is missing is the data, at the scale the problem demands. Bringing the structural assessment of ageing structures into everyday practice still faces challenges of access, repeatability, quantified damage, non-contact measurement of the structural response and cost. This talk argues that UAVs are the missing link. It reviews some of the most relevant proposals published in recent years by the drone community and discusses how, combined with the methods developed in the laboratory, they could allow structural assessment to be deployed massively on real bridges, as well as the questions of accuracy, regulation and trust that remain open before that becomes routine.

S1/2. Drone Design, Development and Communications

Parametric Design and Formless Composite Manufacturing of UAV Structures Using Laser-Cut Airframes and Additive-Manufactured Functional Cores

Christian Schmid[1*], Quentin Hirtl[2], Ehrlenbach Markus[1], Michael Petke[3], Lukas Matthias[4]

[1] FH Kufstein Tirol, University of Applied Sciences, Smart Products and AI supported Development, Drone Engineering, Industrial Engineering
[2] FH Kufstein Tirol, University of Applied Sciences, Smart Products and Solutions, Industrial Engineering, Drone engineering
[3] FH Kufstein Tirol, University of Applied Sciences, Smart Products and AI supported Development, Industrial Engineering, ERP
[4] FH Kufstein Tirol, University of Applied Sciences, Smart Products and AI supported Development, Industrial Engineering

The production of carbon fiber-reinforced structures of Unmanned Aerial Vehicles (UAVs), especially wing-based aircraft with a wingspan of approx. 1 m or more, is a multi-stage process based on the use of molds and devices. For series production, this approach has been tried and tested for many years and is commercially successful. If variants or scaling of the systems is required, the modification or new construction of the molds is necessary. This leads to high costs and long lead times. In order to enable economical and flexible production even in small quantities of drones, a production process based on the additive material extrusion process (MEX) was developed, which enables the moldless production of scalable fixed-wing drones while simultaneously reducing lead time and the required process steps. In the Presentation, the developed process will be compared with conventional production and presented in detail. The aim of this work is to investigate the potential of the developed process compared to the conventional multi-stage process in detail.

Lyrebird: Bringing DJI SDK-Compatible UAVs into the MAVLink Multi-Robot Ecosystem

Alejandro Jarabo-Peñas[1*], Edouard George Alain Rolland[1*], Juan Bravo-Arrabal[1*], Patrik Dominik Pördi[1*], Kilian Meier[2], Anders Lyhne Christensen[1*]

[1] SDU UAS Center, MMMI, University of Southern Denmark (SDU), Odense, Denmark
[2] Faculty of Engineering, University of Bristol, Bristol, UK

However, their closed and proprietary interfaces make them difficult to integrate into autonomous robotics experiments, where perception, coordination, and control are often built around open protocols and frameworks such as MAVLink, PX4, and ROS 2.

We present Lyrebird, an open-source abstraction layer for DJI UAVs ranging from low-cost consumer models to enterprise platforms. Lyrebird translates standard interfaces into DJI-specific SDK operations, thereby presenting supported UAVs as MAVLink-compatible vehicles. Lyrebird runs on the Android device or remote controller connected to the UAV, allowing ground-station software to control the aircraft without directly interacting with DJI's SDK.

Through MAVLink 2, Lyrebird provides telemetry, flight control, vehicle configuration, autonomous waypoint missions, and camera and gimbal control. HTTP and TCP complement MAVLink for higher-throughput data transfer and functionalities that do not map naturally onto MAVLink messages. Lyrebird also provides a unified Python API, ROS 2 interfaces following PX4-style conventions, automatic discovery and identification of multiple UAVs on the same network, and live video streaming to external applications.

Lyrebird builds on WildBridge, an earlier version deployed for multi-UAV control in wildlife-monitoring and search-and-rescue scenarios. We characterise communication latency, telemetry and control performance, video streaming, and multi-UAV operation. Flight experiments include up to eight UAVs, with six DJI platforms integrated alongside two PX4-based drones and controlled through QGroundControl in Mission and Offboard modes.

By exposing DJI UAVs through standard robotics interfaces, Lyrebird reduces hardware integration effort and accelerates the transition from software development to real-world experiments. Control, coordination, and autonomy software can therefore be reused across single-, multi-, and heterogeneous-UAV systems with limited platform-specific adaptation. Software and documentation are openly available online (github.com/SDU-UAS-Center/lyrebird).

DroneCAST: A Software-Defined Radio Implementation and First Flight Demonstration of a Drone-to-Drone Communication System for Urban Airspace

Lukas Marcel Schalk*, Jan Patrick Gerhards, Miguel Angel Bellido-Manganell

[1] *German Aerospace Center (DLR)*
[2] *Institute of Communications and Navigation*
[3] *Communications Systems Department*

Urban Air Mobility (UAM) and Unmanned Traffic Management (UTM) have advanced in recent years, and it becomes clear that within these concepts, reliable communication systems are necessary for safe, scalable, and autonomous flight. Direct drone-to-drone (D2D) communication in particular is essential for safety-critical applications such as collision avoidance. However, urban environments impose severe challenges for the wireless channel, including dense multipath, non-line-of-sight propagation, high node mobility, spectrum scarcity and stringent latency and reliability requirements.

Since 2024, the German Aerospace Center (DLR), together with industry partners, has been developing a first demonstrator of DroneCAST (Drone Communications and Surveillance System), a D2D system whose design is tailored to these conditions. DroneCAST's core is a robust waveform design based on Orthogonal Frequency-Division Multiplexing (OFDM), Dual-Carrier Modulation (DCM), midambles, and LDPC codes to account for the rich multipath environment and rapidly changing channel conditions. It operates in the C-band (5,030–5,091 MHz) with up to 5 MHz bandwidth, foreseen for future unmanned aircraft systems (UAS) communication.

In this work, we present the first real-hardware implementation and flight demonstration of DroneCAST, moving from prior measurement-based simulation to a working over-the-air system. The physical layer is implemented in GNU Radio, running on Ettus USRP B210 software-defined radios (SDRs) and Intel NUC computers integrated onto our hexacopters. Following laboratory validation, we conducted an initial flight trial with two drones and one ground station in an urban collision avoidance scenario. Both drones broadcast their position and ID via DroneCAST and received each other's signals, while the ground station tracked both. We successfully tracked the drones in the air and on the ground with sub-10 ms latency and consistent packet reception, with only occasional packet loss. We present our approach, discuss the challenges encountered and the solutions developed, and outline the next steps toward developing a full DroneCAST demonstrator.

From Actuators to Trajectories: An Open-Source PX4–ROS 2 Architecture for UAV Autonomy

Patrik Dominik Pördi[1*], Anders Christensen[2, 3], Juan Bravo Arrabal[1]

[1] *University of Southern Denmark*
[2] *University of Southern Denmark Dronecenter*
[3] *University of Southern Denmark Climate Cluster*

Uncrewed aerial vehicle (UAV) research and development is characterized by recurring engineering challenges in flight control, sensor integration, and autonomous behaviour implementation. Over the past decade, open-source software frameworks have matured considerably, becoming widely adopted foundations for UAV research and development. However, limited visibility and insufficient knowledge transfer have resulted in recent architectural advances remaining underutilized, with many existing workflows continuing to rely on integration paradigms that predate recent developments.

This study presents a reference architecture for implementing custom autonomous behaviours using off-the-shelf autopilot hardware and a fully open-source software stack. The architecture integrates recent developments in the open-source UAV ecosystem, including the PX4 ROS 2 Interface Library's Control Interface for external modes and setpoint interfaces, with ROS 2 providing a standardized communication layer and DDS-based middleware enabling distributed system integration. The interfaces support a broad range of control abstractions, from navigation tasks to direct actuator control for low-level research applications and high-level trajectory planning. A central feature is a unified ROS 2 interface through which custom autonomy can coexist and interact with native PX4 modes while maintaining integration with PX4 mode management and failsafe mechanisms. Furthermore, the architecture generalizes across multirotor, fixed-wing, and VTOL platforms.

The contribution is twofold. First, the work provides a practical and reproducible demonstration of scalable, safety-aware, and maintainable UAV autonomy built upon established open-source tooling. The architecture was validated through software-in-the-loop simulations and experimental flights on Pixhawk-based platforms. Second, it presents a structured technical assessment of the open-source UAV ecosystem from a developer and researcher perspective. The analysis focuses on software architecture, interface abstractions, and middleware design rather than treating the flight stack as a black box, with the aim of lowering the adoption barrier for modern open-source flight software in both research and industrial applications.

5G-Enabled UAV Control Applications: Experimental Evaluation of Network and Computing Architectures

Brais Iglesias Otero*, José Manuel Molina Casal, David Carramiñana Jiménez, Luca Bergesio, Juan Alberto Besada Portas

[1] *Information Processing and Telecommunications Center (IPTC)*
[2] *Universidad Politécnica de Madrid*

Despite the increasing availability of 5G networks, there is still limited experimental evidence comparing public and private deployments, mmWave communications, and distributed processing architectures for real UAV applications.

This paper presents an experimental evaluation of 5G-enabled UAV communications through a campaign comprising 27 flights comparing public and private 5G deployments, including sub-6 GHz and mmWave operation in the latter. In addition to network characterization experiments (12 flights), a vision-based UAV application (15 flights) is evaluated under three computing architectures: onboard processing, Multi-access Edge Computing (MEC), and remote cloud computing. The study analyzes network-level measurements, including throughput, latency, and packet loss, flight-related geometric factors, such as altitude and distance to the serving antenna, and application-level metrics, such as image-processing time and end-to-end latency. The influence of flight-related geometric factors on network performance is statistically assessed using Spearman's rank correlation to quantify associations between geometric and network variables, complemented by permutation-based feature importance to estimate the relative contribution of each factor to the observed network performance.

The experimental results show that private 5G deployments provide significantly more stable communication conditions than public networks, enabling lower latency and higher throughput for latency-sensitive UAV applications. Furthermore, mmWave communications substantially improve downlink throughput and latency under favorable propagation conditions, while their benefits in the uplink remain limited due to practical deployment constraints. Regarding computing architectures, the results highlight the trade-off between communication dependency and computational capacity. Although cloud-based processing introduces additional communication delay, its substantially lower image-processing time compensates for this overhead, resulting in the lowest overall end-to-end latency among the evaluated distributed architectures. Nevertheless, its performance remains strongly dependent on network conditions.

By jointly evaluating public and private 5G deployments, sub-6 GHz and mmWave communications, flight-related geospatial factors, and different computing architectures under real flight conditions, this work provides a comprehensive experimental characterization for 5G-enabled UAV applications.

S3. Guidance, Navigation, and Control

Uncertainty-Aware Adaptive Multi-Objective UAV Path Planning via Fuzzy Priority Adaptation and Preference-Conditioned Reinforcement Learning

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Conventional multi-objective UAV path planning assigns fixed relative priorities to competing objectives—path length, energy consumption, mission time, and safety—even though the conditions that determine what "optimal" should mean change during flight. This paper proposes a closed-loop planning framework in which measured environmental uncertainty and operational conditions dynamically determine objective priorities. An online uncertainty estimator aggregates localization, sensing, wind, and obstacle-prediction uncertainty from signals available to a real avionics stack, and a risk assessment stage translates these, together with the operational context, into collision and energy risk. An interpretable fuzzy inference engine then maps uncertainty, risk, battery state, and obstacle density to a time-varying preference vector over the mission objectives. The preference vector steers a single preference-conditioned deep reinforcement learning policy, trained with vector-valued rewards over the full preference space, so priorities can be adapted at every decision step without retraining. Simulation experiments under progressively escalating uncertainty show that fixed-priority planners degrade substantially as uncertainty increases, whereas the proposed adaptive mechanism preserves mission success and reduces collisions; ablation studies attribute this gain to per-step priority adaptation itself, rather than to the learning architecture or the fuzzy machinery. The framework is further demonstrated on a realistic beyond-visual-line-of-sight medical-delivery mission across the Saronic Gulf, using representative Greek airspace geofences and real wind forecasts, where the policy trained in the abstract environment transfers without retraining. The results support adaptive objective prioritization as a practical, interpretable layer between situation assessment and learned planners.

Towards Offshore Recovery: Tether Force Sensing for Admittance Guided UAV Landing

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The use of a tether cable for Unmanned Aerial Vehicle (UAV) recovery on mobile platforms such as sea faring vessels is an underexplored area. This presents an opportunity to reduce dependence on conventional landing systems while increasing the range of environmental and weather conditions under which UAVs can be safely and autonomously recovered. While a UAV flying with a tether cable can be more limited than an unrestrained UAV, this physical link can be exploited as a safer tracking system. The tether provides a real-time physical reference to a moving landing point that conventional vision and GPS systems can fail to track. Building on previous simulation work that proposed the use of admittance control to generate a landing trajectory, we propose a lightweight onboard tether force sensing system capable of measuring the force vector required for the practical landing strategy. This approach improves existing landing systems that depend on external position estimates by using real-time tether tension feedback measured directly onboard. The force sensing system comprises of a passive 2-axis gimbal with two encoders and a strain gauge to measure the tether angles and tension, respectively, mounted on the UAV at the tether attachment point. An onboard companion computer resolves the measurements to a force vector, that the admittance controller uses to generate the setpoints which define the landing trajectory. The system was tested on a quadcopter with a companion computer used as an interface between the sensor and flight controller. Results demonstrate the ability of the system to accurately measure the tether forces and successfully guide the UAV to the landing platform using the generated trajectory. The proposed pairing of force sensing and onboard trajectory generation using only the tether as a guide is a novel contribution towards more robust autonomous UAV offshore recovery systems.

Energy-Budgeted UAV Swarm Coverage of Time-Varying Densities: Instantaneous Guarantees, Runtime Certificates, and What Downwash Costs Them

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Persistent aerial monitoring asks a swarm of endurance-limited UAVs to keep its sensing where a moving importance density puts its mass, at every instant and under a hard battery budget. Existing guarantees fall into two camps: coverage control proves asymptotic convergence to a local optimum, with no approximation ratio and no energy constraint, while distributed submodular maximization gives regret bounds for agents committing one action per round, with no path budget. Neither tells an operator what a battery-feasible plan is worth now.

We present Distributed Budget-and-Locality-aware Greedy (DBLG), a planner in which each UAV commits a battery-feasible set of sorties from its own motion-primitive library using only local information, and we prove an instantaneous per-time-step constant-factor guarantee against the same-budget clairvoyant optimum. Because that worst-case factor is loose, DBLG also emits a distributed runtime certificate that bounds the optimality gap on each instance, averaging 0.96 of that optimum. Our sharpest theoretical result is a predictability dichotomy: for forecastable densities the guarantee holds uniformly in the drift rate, whereas for unpredictable ones we prove a tight, randomization-robust achievable ratio that degrades once the number of reachable configurations exceeds the swarm's covering capacity. The hard axis is predictability, not speed.

We then ask what physics costs these guarantees. The planner scales to 2000 agents while matching centralized greedy to three decimals, but an executed aerial rung with 6-DOF rotorcraft and inter-UAV downwash shows that the "locality is free" property breaks in dense formations, at an interaction range larger for every swarm beyond the smallest we flew, and surviving replacement of both the rigid-body engine and the controller. Extending to densities a swarm must find, an adversarial audit of our own search planner exposes two ways a distance-discounted planner silently stops moving. This is a theory-and-simulation study; the theorems are the contribution.

Towards Plug-and-Fly Quadrotors: Minimal Identification and Automatic Tuning with Incremental-Based Flight Control

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Uncrewed Aerial Vehicles (UAVs) commonly rely on accurate dynamic models and extensive system identification to achieve high-performance flight control, which often requires expert knowledge and complex experimental trials, representing significant barriers to the rapid deployment of new platforms. Furthermore, these processes must be repeated whenever the configuration changes due to modifications in geometry, payload, or propulsion systems, limiting the adaptability and ease of reconfiguration of autonomous aircraft. Incremental control strategies, such as Incremental Nonlinear Dynamics Inversion (INDI), overcome much of this complexity by requiring only the actuator control effectiveness rather than a complete dynamics model. Accounting for such advantage, this paper proposes a dedicated framework for quadrotors controlled with incremental strategies that combines minimal system identification with automatic controller tuning, enabling rapid controller deployment with limited prior knowledge of the aircraft.

The underlying methodology relies on two sequential steps: identification of the actuator effectiveness, followed by automatic tuning of the INDI controller. The identification process estimates the control effectiveness matrix through a dedicated procedure, in which each attitude control channel is independently excited, and the resulting estimated angular accelerations are processed through linear regression to estimate the different components of this matrix. Subsequently, the gains of the linear feedback component of the controller are automatically tuned by minimizing a multi-objective cost function that accounts for transient response, oscillatory behaviour, and control effort.

The proposed framework is first validated in simulation, demonstrating accurate estimation of the control effectiveness and successful controller adjustment. Experimental validation is then performed in two stages: identification and tuning on a dedicated gimbal test bench, followed by free-flight experiments. The obtained results demonstrate the feasibility of an almost fully autonomous configuration of the INDI-based flight controller with minimal modelling and identification effort, achieving a stable autonomous flight without any prior knowledge of the characteristics of the UAV.

S4. Artificial Intelligence Applications for Drones

Artificial Intelligence as an Enabler of Operational Resilience in Autonomous UAV-AutoID Systems Operating in Dynamic Indoor Environments

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The increasing deployment of autonomous UAV-AutoID systems in warehouses, production halls, and other industrial facilities has created a growing need to ensure their operational resilience under dynamic indoor conditions. These environments are characterized by spatial constraints, changing lighting, electromagnetic interference, sensor degradation, communication limitations, and variable mission requirements. While existing research on artificial intelligence in unmanned aerial vehicles primarily focuses on navigation, localization, computer vision, obstacle avoidance, and autonomous flight control, the role of AI as a mechanism for enhancing the resilience of the complete UAV-based system remains insufficiently explored. This paper proposes a system-level framework for integrating artificial intelligence into the operational resilience of autonomous UAV-AutoID systems operating in dynamic indoor environments. Building upon the M-UAV resilience assessment method, the proposed approach incorporates AI-based mechanisms for disturbance detection, operational risk prediction, adaptive mission planning, intelligent decision support, and real-time mission reconfiguration. The framework considers interactions among the UAV platform, AutoID technologies, onboard perception and control software, communication infrastructure, data-processing components, and the operational environment. It explains how machine learning, computer vision, Edge AI, and adaptive decision-making can support early identification of adverse conditions, selection of corrective actions, and maintenance of acceptable system performance despite disturbances. The proposed concept extends conventional resilience assessment by introducing AI as a proactive resilience-building mechanism rather than only a tool for flight automation. It therefore enables a transition from retrospective evaluation toward predictive and adaptive resilience management. The study provides a foundation for further research on intelligent, reliable, and self-adaptive UAV systems for Industry 4.0, Logistics 4.0, automated inventory, and industrial inspection applications.

From Object Detection to Conflict Assessment: A Safety-Oriented Uncertainty Framework for Monocular UAS Detect-and-Avoid

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Monocular cameras are attractive sensors for Detect-and-Avoid (DAA) on lightweight unmanned aircraft systems (UASs) because they are passive, low-cost, easy to integrate, and can support the detection and tracking of non-cooperative or electronically non-conspicuous airborne objects. Their safety-relevant performance, however, cannot be inferred from object-detection metrics alone because errors propagate through the perception chain: image acquisition and formation, target detection and classification, bounding-box localization, physical-size prior selection, monocular ranging, temporal tracking, and closing-speed estimation. This paper develops a safety-oriented uncertainty framework for monocular airborne conflict detection as a residual onboard layer in a layered UAS conflict-risk mitigation architecture. The framework distinguishes uncertainty arising from detection failures, class confusion, physical-size priors, target pose and aspect angle, bounding-box localization, temporal association, and camera and image-formation characteristics. These include sensor resolution and distance-dependent loss of projected target detail, intrinsic and extrinsic calibration, optical distortion and off-axis degradation, exposure time and frame rate, motion blur, sensor noise, compression, contrast loss, and background clutter. A large purpose-built labeled air-target image dataset, supplemented by suitable public datasets, is used to estimate component-level error distributions across target classes and operating conditions. These distributions are propagated through a pinhole-based ranging model and temporal closing-speed estimators to quantify total system error as a function of distance, relative geometry, target class, image quality, and camera configuration. The framework is evaluated using a curated flight-test dataset with RTK-derived ground-truth separation between observing and intruding aerial platforms. The analysis yields class- and distance-dependent uncertainty budgets, safety margins, and operating limits for UAVs, light and transport aircraft, helicopters, gliders, balloons and airships, birds, and kites. By identifying the dominant error sources across relevant regimes, the framework supports evidence-based assessment of monocular sensing for low-altitude UAS conflict detection.

Automatic Aerial Identification Model for Baleen Whales Using Drones

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The use of unmanned aerial vehicles (UAVs) has significantly improved cetacean research by enabling the collection of high-resolution imagery used in several research topics, such as individual identification. This study presents an automated deep learning framework for identifying mainly fin whales (*Balaenoptera physalus*), but also sei whales (*Balaenoptera borealis*) and Bryde's whales (*Balaenoptera edeni*) from drone imagery. These species exhibit a characteristic dorsal pigmentation right after the blowhole, known as chevron, which is unique to each individual and remains stable throughout its lifetime, making it a reliable natural marker for photo-identification. UAV-based surveys also improve identification efficiency, increasing the success identification rate from 60-65% using conventional methods to 75-80%, while providing a standardized identification approach that facilitates comparisons and data sharing among different research groups. The proposed framework consists of three sequential stages: head localization, species classification and individual identification based on the chevron pigmentation pattern. The first two stages employ YOLO models trained to detect the head and classify the species. For individual recognition, a hybrid architecture combining a ResNet backbone with a recurrent component, and a Siamese neural network was developed to identify and compare pigmentation patterns with a reference catalogue. The current model has been trained primarily using fin whale imagery and includes a database of over 400 individuals. Although the species-recognition step has been already incorporated into the model, ongoing work aims to improve the Sei and Bryde's identification through expanded datasets and model refinement. Furthermore, the current research is focused on implementing real-time onboard identification during UAV surveys, thereby increasing the efficiency of field research. Ultimately, the proposed model is intended to support long-term global monitoring of baleen whale populations by providing a standardized identification framework that facilitates data sharing and collaboration among organizations working on baleen whale research and conservation.

Physics-Informed Predictive Control for a Fixed-Wing UAS under Uncertain Flight Dynamics

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The variation in unmanned aerial system dynamics during flight poses significant challenges for predictive flight control when the presence of external disturbances and accurate aerodynamic models are not available throughout the flight envelope. This research proposes a physics-informed neural predictive control framework for the longitudinal dynamics of a fixed-wing unmanned aerial system. A neural predictor is trained using data collected at a limited set of flight points, while partial knowledge of the aircraft dynamics is incorporated through physics-based constraints during training. The resulting model is then used as the internal predictor of the model predictive controller and evaluated at operating conditions excluded from the training dataset. To account for residual model mismatch and external perturbations, a generalized proportional-integral observer is introduced to reconstruct a lumped disturbance. The estimated disturbance augments the predictive model rather than being assumed to act through the control channel, enabling the controller to account for disturbance effects that may not be directly cancelable. Numerical experiments using the UAS-S45 Bálaam system evaluate longitudinal reference tracking at trained and completely unknown operating conditions, with additional disturbance scenarios introduced exclusively during validation. The proposed framework combines physics-guided learning, online disturbance reconstruction, and predictive control to reduce dependence on an accurate global aircraft model while maintaining closed-loop performance under uncertain flight dynamics as evidenced by yielded results.

Development and Evaluation of an Edge AI System for Real-Time UAV-Based Photovoltaic Thermal Inspection

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Defect detection in photovoltaic installations increasingly relies on UAV thermal imagery followed by offline post-processing, which delays critical maintenance decisions. Real-time on-board inspection resolves this latency but is strictly bounded by the edge hardware's computational and power capacities.

To address this, we developed a complete edge AI system for real-time UAV-based photovoltaic inspection integrating an NVIDIA Jetson Orin NX module on a DJI M300 RTK drone. Its pipeline includes preprocessing of thermal imagery, YOLOv12 inference which was fine-tuned on a dataset of distinct thermal anomalies (e.g., hotspots, bypassed diodes) and Non-Maximum Suppression (NMS) post-processing. While YOLOv12 achieves real-time speeds on desktop GPUs, its raw execution on edge devices introduces critical latency bottlenecks. To maximize throughput within the hardware limits, TensorRT Post-Training Quantization (PTQ) was systematically evaluated across FP32, FP16, and INT8 formats.

The results indicate the system's energy viability, recording a maximum power consumption of 14.4 W and a temperature of 42.8 °C. The INT8 format (42.73 FPS) underperformed compared to FP16 (44.19 FPS) in the inference. This is caused by the quantization/dequantization (Q/DQ) node execution. The lack of native INT8 kernels for YOLOv12's advanced linear attention mechanisms forces a fallback from Tensor Cores to the CPU. Furthermore, INT8 quantization is followed by a drop of the mean average precision (mAP) across the dataset compared to FP16 (2.06%).

Results validate the FP16 format as the optimal deployment configuration for this edge AI system. Achieving an end-to-end processing latency of 24.80 ms, the system successfully processes sequential thermal image frames at 30 Hz with zero frame drops, enabling reliable and immediate in-flight diagnostics.

AI-Driven Analysis of Drone Imagery for Flash Flood Damage Assessment

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Natural disaster management is constrained by short response windows that hinder systematic observations, highlighting the need for rapid and effective tools to support emergency services. Drones are now an integral part of disaster management practices, providing valuable support for real-time emergency response, impact forecasting, and post-disaster damage assessment. Their integration with artificial intelligence (AI) further enhances these capabilities through fast, scalable, and accurate data processing. This study presents a real-world application of drone-based and AI-driven techniques for emergency management following the severe flash-flood event that affected Valencia (Spain) after a cut-off low event on 29 October 2024. A multi-sensor dataset combining RGB imagery, LiDAR, multispectral data, and gas measurements was used to: (i) generate a detailed topographic survey of the most affected area and support a basic flood simulation; (ii) identify and assess damaged infrastructure; (iii) quantify sludge accumulation zones and classify sludge types through machine-learning analysis of spectral responses; (iv) detect waste accumulation and vehicle clustering using deep-learning models; and (v) evaluate air quality in the most impacted urban sectors. The results demonstrate that integrating drone observations with AI-based analysis provides valuable near real-time information for disaster response and recovery. This approach improves situational awareness, supports more reliable decision-making, and enables more effective mitigation actions. The combination of these technologies offers a flexible, safe, and precise alternative to conventional remote sensing and field-based methods, helping to bridge critical gaps in post-disaster assessment and emergency management.

Set the Rules, React to Change: Extending Natural-Language Drone-Swarm Coordination with Constraints, Events, and Operational Knowledge

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Natural-language control can make drone swarms easier to direct, but one-shot commands are insufficient for missions with standing policies, changing priorities, and time-critical observations. We extend Swarm-Steward—a natural-language multi-robot coordination system that uses an LLM-based multi-agent architecture to ground operator requests and dispatch deterministic robot actions—with a mission-governance layer for human-supervised drone swarms. The system interprets operator intent and selects mission tools and predefined robot behaviors; drone motion, sensing, and interaction are executed through deterministic action primitives and controllers. Operators can define enduring constraints in ordinary language, such as “Never enter the helicopter landing zone” or “Keep all drones at least 10 m apart.” These instructions are translated into typed declarative rules and compiled into deterministic predicates over telemetry, map relations, planned trajectories, tool parameters, time, and action history. Constraints specify conditions that must remain satisfied and are validated against their semantics and the existing rule base before activation. They mediate LLM-selected plans before tool invocation, queueing, and execution, and during runtime monitoring, blocking violations or triggering replanning. Events use the same rule language and checking backend, but define operator-authored condition-response policies; when a condition becomes true, they can notify the operator, cancel or reprioritize queued actions, initiate replanning, or dispatch predefined robot actions. For example, “If any drone detects a person, stop its sweep and orbit the location” connects a perception event to a deterministic follow-up behavior without a new operator command. An Operational Knowledge Agent retains mission vocabulary, aliases, preferences, and reusable procedures, including conventions such as an operator’s preferred directional reference frame, enabling later instructions to be grounded consistently without modifying canonical mission entities.

Deep Event Processing: From Microsecond Spatio-Temporal Streams to Aerial Target Forecasting

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The proliferation of small unmanned aerial vehicles (UAVs) introduces critical surveillance and airspace security challenges that conventional frame-based optical systems struggle to resolve. Standard RGB sensors are fundamentally constrained by fixed exposure periods, which induce severe motion blur when capturing agile, high-velocity targets, while their limited dynamic range leads to information loss under low-light or backlit sky conditions. Neuromorphic vision sensors, or event cameras, present an asynchronous sensing paradigm that overcomes these degradation mechanisms by reporting per-pixel log-intensity variations with microsecond-level temporal precision and high dynamic range exceeding 120 dB. By eliminating synchronous frame exposure, event sensors suppress static visual backgrounds and encode high-frequency kinematic patterns without blur, drastically diminishing data throughput and transmission latency. These sensor characteristics unlock extensive methodological possibilities across aerial perception pipelines, spanning low-latency detection, multi-target tracking, trajectory forecasting, and state estimation. The ultra-fine temporal resolution captures the micro-motion signatures of high-speed rotating propellers, enabling frequency-domain tachometry, orientation estimation, and fine-grained classification against biological distractors such as birds and insects. Crucially, the sparse spatio-temporal streams facilitate diverse processing paradigms. Asynchronous event data can be discretized into dense voxel grids, compressed into time surfaces, or directly ingested as continuous four-dimensional point clouds via permutation-invariant neural backbones and graph architectures, avoiding temporal quantization artifacts. Furthermore, deploying event streams onto spiking neural networks and neuromorphic processors realizes end-to-end edge inference under strict power constraints. When paired with traditional optical streams in multimodal architectures, event data effectively compensates for the dynamic and illumination failures of standard imagery, while RGB features supply stationary spatial context. Neuromorphic sensing establishes a foundational architecture for real-time, low-power counter-UAV infrastructure capable of continuous tracking, intent prediction, and aerial threat mitigation in unstructured operational domains.

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S5. Drones in Rangelands, Agriculture, and Forestry

Multi-Robot Systems for Precision Agriculture

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Biologically complex polyculture environments require multi-robot systems capable of monitoring and intervening under dynamic field conditions. Developed within the multi-institutional Robotic Intercropping initiative, this work reviews the relevant literature and proposes a conceptual framework for designing multi-robot systems for sustainable precision agriculture. The framework addresses how complementary robotic platforms can be integrated into field-robotics workflows, where system-level capabilities emerge from interactions between agents.

The review identifies three recurring levels of inter-agent interaction. Cooperation, where agents pursue a shared objective while acting independently, appears to be the most common. Coordination, involving state exchange and task management to improve efficiency and avoid conflicts, is less frequently implemented. Collaboration, where joint outcomes are enabled by complementary capabilities, remains comparatively rare. These interaction levels are complemented by a distinct but related dimension of system design, characterized along three dimensions: environmental complexity, mission complexity, and independence from human input.

This classification provides more than a descriptive overview: the relationship between interaction level, autonomy, and system architecture establishes a structured basis for multi-robot system design. We propose a layered framework that maps these dimensions to architectural choices and guides the deployment of UAV–UAV and UAV–UGV systems for agricultural monitoring and intervention. The framework follows a hybrid control paradigm, combining high-level human supervision with autonomous multi-robot operation. Human operators define objectives, priorities, and safety constraints, while robotic teams perform task allocation, local decision-making, and mission replanning through hierarchical control when tighter coupling is required.

A representative workflow illustrates this approach: an operator specifies a scouting objective, a UAV team performs multi-robot coverage planning to identify drought stress or pest presence, and UGVs subsequently execute targeted interventions. Informed by current field deployments and extended toward robotic intercropping scenarios, the framework supports the integration of aerial and ground platforms into end-to-end agricultural robotics pipelines spanning sensing, analysis, and intervention.

Using drones to derive fuel load estimates in semi-arid rangelands

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Fires are a key process in landscapes globally. However, the frequency, size, and intensity of wildfires are shifting. In the Great Plains of North America, wildfires are larger, more frequent, and burn at higher severities. These changes have resulted in megafire outbreaks, where multiple large-scale (> 10,000-ha) fires occur simultaneously and destroy infrastructure and livestock. Understanding the fuel loads that drive these megafires in rangelands at a landscape scale is crucial for mitigation and planning. The objective of this study was to estimate herbaceous fuel loads in a rangeland system using high-resolution drone imagery and field sampling and to determine how vegetation height and status (invasive/native grasses and forbs) affect fuel load. We used the 428,352-ha Smokehouse Creek Fire that burned across the south-central United States, as a case study. We collected ~800 ha of RGB imagery with a Trinity Pro fixed-wing drone and collected 225 fuel load plots from four different sites within the burn scar. To calculate fine fuel load (kg/ha) from the ground, 0.5 by 0.5 m herbaceous vegetation plots were clipped, dried, and weighed. Fine fuel load (cm^3) estimates from the drone were calculated by generating a digital elevation model (DEM), taking the mean DEM value from each plot, and multiplying it by pixel size. We ran a two-way ANOVA to analyze the impacts on vegetation height, status, and vegetation height-status on fuel loads (cm^3 or kg/ha). In both methods, vegetation height had a significant impact on fuel load (drone: $p = 2 \times 10^{-16}$; ground: $p = 4.85 \times 10^{-9}$). Status and vegetation height-status did not significantly affect fuel load in either method. This indicates that managers looking to reduce fine fuel load should focus on reducing overall vegetation height, as opposed to exclusively targeting tall invasive grass/forb patches.

Closing the Granularity Gap: A Multi-Sensor UAV Framework for Detecting Agronomic and Ecological Microstructures in Agricultural Landscapes

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Modern precision agriculture increasingly demands the detection of small-scale field features — termed microstructures — that fall below the spatial resolution of conventional satellite-based remote sensing. These microstructures, whether biotic or abiotic, carry significant implications for farm operations, biodiversity conservation, and sustainable land management. This contribution presents a cumulative research framework comprising three complementary UAV-based case studies, each targeting a distinct sensor domain and detection challenge within Central European agricultural landscapes.

The first study investigates stone detection on arable land using UAV-mounted thermal cameras. Laboratory experiments and field trials demonstrate that surface stones exhibit significantly higher temperatures than surrounding soil during cooling phases, driven by differential thermal inertia—particularly under high soil moisture and declining air temperature—enabling reliable, non-invasive identification of stones that pose risks to agricultural machinery.

The second study employs UAV-based LiDAR to detect burrows of the European hamster (*Cricetus cricetus*), a critically endangered species whose habitat intersects with intensive farming. A geostatistical algorithm for identifying local elevation minima in high-density 3D point clouds achieved detection rates of up to 87%, offering a scalable alternative to manual surveys and supporting the reconciliation of species conservation with agricultural practice.

The third study addresses the detection of invasive plant species (including *Heracleum mantegazzianum* and *Fallopia* spp.) using multiscale, multi-sensor remote sensing from UAV and satellite platforms. By integrating phenological field observations with object-based classification algorithms, optimal detection windows and sensor configurations for mapping invasive neophytes were identified.

Collectively, the three studies illustrate how domain-specific UAV sensor deployments—thermal, LiDAR, and multispectral—can systematically address the resolution gap limiting conventional remote sensing at the sub-field scale. The framework demonstrates that transitioning from area-based to object-based monitoring is technically feasible and practically relevant for diverse agricultural and ecological management tasks.

GrapeSense-VISION: Vineyard Intelligence System for Interactive Observation and Navigation using Drone-Based Deep Learning

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Grape crops are vital for global agriculture, including food security and the wine-making industry. Traditionally, effective vineyard management requires labor-intensive scouting to evaluate ripeness progression and detect plant disease onset, a process that is time-consuming and often catches issues too late for intervention. The GrapeSense project offers a scalable and modern approach to viticulture, leveraging drone-captured imagery and deep learning to automate vineyard monitoring. Working with wineries in California, aerial images were collected across multiple drone flights spanning a complete growing season. These geotagged images are processed through a two-stage deep learning pipeline. First, a YOLOv8 object detection model localizes individual grape clusters and leaves, achieving an mAP50 of 85.0%. Second, specialized transfer-learning classifiers evaluate the localized regions: a ResNet-152 model categorizes grapes into one of seven ripeness stages with 93.28% accuracy, while a fine-tuned ResNet-18 architecture identifies the presence of Black Rot, Esca, or Leaf Blight with 99.61% accuracy. To translate these outputs into actionable insights, this work introduces GrapeSense VISION, an interactive dashboard that aggregates classification results onto a satellite map of the vineyard. Each detection is plotted at its GPS-extracted coordinates with color-coded markers indicating spatial distributions of ripeness levels and disease hotspots. The dashboard also includes temporal filtering by flight date, ripeness distribution charts, and interactive image monitoring views. By intersecting drone-captured data, automated visual analysis, and an accessible interface, GrapeSense provides a practical tool for growers to optimize harvest scheduling and prioritize targeted disease treatments, reducing both labor costs and potential crop-yield loss.

From Fire Detection to Forest Recovery: An Integrated UAV-IoT System for Wildfire Monitoring and Reforestation

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Wildfires and the degradation of forest land pose a major threat to ecosystems, particularly in Northern Thailand, where the dry season brings recurrent fires, severe haze and long-term biodiversity loss. As part of **Project FireFly**, this work presents an integrated UAV-based approach spanning the full cycle from the early detection of forest fires to the restoration of burnt landscapes. For **fire monitoring**, low-cost IoT ground modules measure temperature, humidity and smoke beneath the canopy. A LoRa mesh network has been implemented for communication between the distributed sensor nodes. As 4G coverage is limited in remote forest areas, a multirotor UAV carrying a 4G-enabled air module acts as a communication relay, collecting sensor data along pre-programmed survey routes while simultaneously surveying the area for fire using a thermal infrared camera. Data is streamed to an online dashboard, where machine learning models provide fire probability estimates for emergency response services. The same UAV-IoT infrastructure is extended beyond fire detection towards **biodiversity monitoring** and assessment of **forest restoration** in areas destroyed by fire. Additional sensors enable wildlife surveillance in remote areas, while aerial surveying of tree health and canopy structure quantifies the carbon sequestration potential of reforested areas. For **forest restoration**, a **UAV-based seed-dropping system** has been developed as part of Project FireFly to enable direct seeding of native tree species. A lightweight carriage mechanism has been integrated with the multirotor platform to release individual seed balls at pre-defined locations. **Field validation** near Chiang Mai, including trials at a restored forest site operated by the Forest Restoration Research Unit at Chiang Mai University, demonstrates the feasibility of the proposed approach combining fire detection, biodiversity monitoring and UAV-based reforestation. The work illustrates how UAV infrastructure developed for wildfire response can be repurposed to support the longer restoration cycle that follows a fire.

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Data-Efficient Field-Scale Mapping of Soil Salinity and Its Spatial Controls Using UAV Multispectral Imagery, Proximal Sensing, and Interpretable Machine Learning

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Accurate characterization of soil salinity is essential for sustainable agricultural management in arid and semi-arid regions, but conventional field surveys are limited by intensive sampling requirements and poor spatial coverage. This study integrated UAV multispectral sensing, near-surface electromagnetic induction (EMI) measurements, PlanetScope imagery, machine learning, and geospatial statistics to map field-scale soil salinity from limited ground observations in Sehb El Masjoune, central Morocco. Ground data included 26 soil samples analyzed for electrical conductivity (EC) and 500 measurements of apparent electrical conductivity (ECa, EM38-MK2) calibrated against laboratory EC.

Spectral and terrain predictors derived from UAV and PlanetScope imagery were used with Partial Least Squares Regression (PLSR), Support Vector Regression (SVR), Random Forest (RF), and a stacked Ensemble Learning Model (ELM). Regression Kriging (RK) was applied to account for spatially structured residuals. ELM achieved the highest predictive performance (R^2 = 0.87; RMSE ≈ 4.15), while RF effectively captured nonlinear spatial variability. RK improvements were model-dependent, with PLSR showing the largest gains (11.1% for PlanetScope and 13.8% for UAV predictors), whereas improvements for RF, SVR, and ELM were limited. SHAP analysis identified terrain variables as the strongest controls on predicted salinity, emphasizing the importance of topography in field-scale salinity patterns. Despite their contrasting spatial resolutions, centimetric UAV and 3-m PlanetScope imagery produced consistent representations of saline–sodic areas. Overall, integrating remote sensing with sparse proximal observations and interpretable machine learning enabled data-efficient salinity mapping, while model formulation and representation of spatial controls were more influential than imagery resolution alone.

S6. Drones in Security and Defense

Attention Focusing and Division of Labour in Swarm Warfare

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In future conflicts, it is highly likely that autonomous machine collectives, also known as “swarms”, will engage each other without *direct* human intervention or supervision. Instead, control over these robotic combatants will most likely be *indirect*, taking the form of communicating strategic objectives, specifying the geographical limits of the area of operations, setting the rules of engagement etc., before deployment. One plausible scenario in the near to medium-term future is the use of an autonomous force of Unmanned Aerial Systems (UAS) to defend sensitive borders in remote, sparsely populated areas (e.g., the arctic region) against any incursion by a hostile swarm or other airborne threat. In this context, the development of distributed autonomous decision-making algorithms capable of improving the performance of the defending swarm without human guidance, e.g., in successfully and efficiently intercepting an enemy force, seems paramount. This specifically requires solving the problem of allocating proportional resources to engage multiple and potentially heterogeneous threats and to approximate optimal division of labour *without central coordination*. In this paper, we propose and evaluate such an algorithm, putting special emphasis on the influence of individual units having to make decisions based on *incomplete* information and using *unreliable* communication channels. Multiple scenarios are tested through Monte Carlo simulation, involving variable balance of power (relative swarm sizes), detection and communication ranges, and intruder strategy (invading “en masse” vs. repeated probing). The results are quantitatively analysed, allowing for the identification of important thresholds.

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Drones and Drone Swarms: Key Players in Securing Critical Infrastructures

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The security of airports, nuclear plants, oil and gas storage facilities, etc. is gaining importance due to geopolitical context. The Padrone.AI project aims to develop a platform helping Critical Infrastructure Owners and Operators manage and secure their assets. Its current implementation focuses on airports. It brings together 17 partners, including four research laboratories and 13 companies. This €6.5 million initiative (ANR-23-DMRO-0009) is supported by the French State and coordinated by the National Research Agency (ANR) under the Défis Transfert Robotique challenge, part of France 2030.

Drones and drone swarms are key players in this layered platform. The first level consists of sensors (LiDAR, vibration sensors, cameras, etc.). When an alert is raised, edge AI determines whether it can be dismissed as a false positive or requires further investigation. If not, an AI-based hypervisor determines the appropriate action. The first step is deploying a ground robot to investigate the alert. The robot assesses whether further investigation is required. If so, the hypervisor can deploy a drone or swarm to gather additional information. If the alert is not dismissed by embedded AI, it is reported to a human, who makes the final decision.

Drones and AI, as key components, raise several challenges. Flying drones near airports is highly regulated worldwide, and authorities require guarantees regarding operational safety and reliability. Although obtaining authorization can be challenging, it is possible for specific operations. In our project, AI introduces an additional level of uncertainty. We therefore focus on two main directions: improving the explainability of AI-based decisions and developing security mechanisms, such as geofencing, to ensure safe and fully controlled operations during missions.

The project started in January 2025. After these 20 months of theoretical work and unitary experimentations, we are now in the process of combining its components around a central backbone.

Funding: This €6.5 million initiative (ANR-23-DMRO-0009) is supported by the French State and coordinated by the National Research Agency (ANR) under the Défis Transfert Robotique challenge, part of France 2030

Operational and practical insights into the use of drones and UxVs in conflicts

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The field of drones and UxV is large and diverse, and research efforts are increasingly addressing a broadening range of issues and applications. One reason for this rapid increase in relevance of uncrewed systems, especially aerial systems, is their use in armed conflict such as in Ukraine since 2022 and, more recently, in the Middle East. What we observe from those conflicts is that the practical needs and the operational reality often differ massively from the guarded reality that many research projects assume. For example, many research efforts assume that communication and localization are pervasively available, which they are often not. As a result, what is observed in the skies of Ukraine is often a stunning feat of engineering where frontiers are continuously pushed, but it is also regularly an unholy amalgamation of hacks, tricks, patches and exploits that often last only days before they stop working. As a commonly discussed example, consider the use of fiber-optic cable to circumvent jamming, which while solving the practical challenges on the ground, are from a research point of view a step backwards. This paper / talk will discuss recent changes and insights of the operational reality of using UxV in cluttered, contested and adversarial environments. This paper and presentation will be something like a literature study, but instead of reporting on the state of the art from a research and scientific point of view, we provide this from an operational perspective. We will do so on the bases of (unclassified and publicly available) recent publications and reports, drawing, on one hand, on the publications from national research labs such as TNO, NLR, VTT, FFI, FOI, RMA, Fraunhofer, and DLR, and on the other hand, on reports from think tanks such as RAND and RUSI, as well as publicly available NATO documents.

SmartPilot: A Lightweight, Low-Power Edge AI Module for Intelligent UAV Operations

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Small UAVs are increasingly relevant to security and defense missions, yet onboard autonomy remains constrained by mass, power, latency, and integration complexity. We present a 22 g edge-AI module, with an accelerator, perception network, and control stack co-designed for a 6 W peak budget, that adds human-supervised perception, tracking, and target-directed control to fixed- and rotary-wing UAVs without replacing the existing flight controller.

A purpose-designed joint detection-and-embedding (JDE) network detects and associates targets in a single inference pass. A reinforcement-learning policy developed and trained in simulation converts its outputs into thrust and roll-, pitch-, and yaw-rate commands. The module therefore occupies the pilot's role rather than the flight controller's, issuing the same high-level commands a human pilot would. The operator retains supervisory authority and immediate override.

The INT8-quantised perception network occupies 0.73 MB and executes in 12 ms at 320 × 320, with 15.2 ms of p99 latency; quantisation reduces mAP@0.5 by only 0.009. Detection achieves 0.746 mAP@0.5 in-domain and 0.614 on the AOT benchmark. Input mapping dominates quantisation error; whole-frame letterboxing reduces AOT mAP@0.5 to 0.127, whereas native-scale cropping restores 0.614.
Closed-loop evaluation covered 350 engagements in a DCS-based simulator, spanning 14 target types and 25 approach geometries, with the physical module commanding an unmodified commercial flight controller. Averaged over flights, field-of-view retention over measurable frames and correct-identity tracking over visible frames both reached 94.7%. The closing rate exceeded 1 m/s for 77.2% of frames, and 47.7% of engagements ended in a successful intercept. Flight trials on physical airframes await authorisation from national authorities.

Hardware–network co-design brings a complete perception-to-control layer within the mass and power envelope of small UAVs, without displacing the existing flight controller.

A Cognitive Framework for Dynamic Level-of-Autonomy Selection in Autonomous UAV Missions

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The increasing deployment of Unmanned Aerial Vehicles (UAVs) in surveillance, inspection, monitoring, and mission-critical applications calls for autonomous systems capable of adapting their Level-of-Autonomy (LoA) to dynamically changing operational conditions. Conventional UAV autonomy schemes often rely on predefined configurations or isolated threshold-based rules, which may provide limited adaptability when environmental, communication, system, mission, and human-operator conditions change concurrently. The present study proposes a framework based on cognitive decision-making, enabling UAVs to dynamically determine the most appropriate LoA during mission execution. The framework combines Bayesian data-driven reasoning with event-driven and anticipatory reasoning to jointly assess environmental complexity, weather conditions, obstacle risk, mission criticality, UAV health, remaining energy, navigation confidence, communication quality, computational resources, operator workload, availability, experience, and preferred autonomy. The framework is evaluated through simulations covering nominal operation, communication degradation, increased operator workload, unexpected obstacle detection, weather deterioration, UAV-health degradation, and combined multi-disturbance scenarios. The proposed approach provides a unified cognitive mechanism for context-aware and event-driven UAV autonomy adaptation, offering a flexible foundation for resilient and human-centered autonomous UAV operations.

S7. Drones in Geospatial Industry

From UAV Data Acquisition to Decision-Led Geospatial Monitoring: Stakeholder Perspectives from Scottish Peatland Restoration

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Peatland restoration requires reliable monitoring across spatial scales, yet the expanding availability of unmanned aerial vehicles (UAVs), satellite Earth observation, geospatial analytics and field-based methods creates an important practical question: where do UAVs provide greatest value within an integrated environmental monitoring workflow? This study explores that question through qualitative stakeholder evidence collected during the development of a geospatial monitoring concept for Scottish peatland restoration. Semi-structured interviews with stakeholders involved in peatland monitoring, hydrology, land management, GIS and remote sensing were analysed thematically to examine current monitoring practices, perceived limitations and opportunities for UAV-supported approaches. The findings indicate that UAVs are valued for providing detailed, site-specific and repeatable observations, but their usefulness is strongly dependent on monitoring purpose and spatial scale. Participants identified limitations associated with weather, data-processing requirements, specialist expertise and the feasibility of repeatedly surveying large numbers of sites. The evidence also indicates that UAV observations cannot replace direct field measurements for several peatland variables and therefore require integration with ground-based and environmental evidence. At larger spatial scales, satellite Earth observation was perceived as offering advantages through systematic and repeatable coverage, while UAVs can provide a higher-resolution layer for selected locations and uncertainties. The study therefore proposes a decision-led geospatial monitoring framework in which satellite observation, GIS, targeted UAV acquisition and field validation are deployed according to spatial scale, environmental variable, uncertainty and decision need. The findings suggest that the future value of UAVs in environmental monitoring lies not simply in acquiring more high-resolution data, but in their targeted integration within multi-source geospatial intelligence workflows.

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Drone-Based Maritime Geospatial Intelligence: Automated Vessel Detection, Positioning and Characterization

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Unmanned Aerial Systems are increasingly used for inspection and mapping in maritime environments, but their integration into operational geospatial workflows remains challenging. This contribution presents a drone-based image analysis framework for transforming aerial imagery or video into actionable maritime geospatial information. The approach combines photogrammetric reconstruction, computer vision and artificial intelligence to detect, locate and characterize vessels in port and coastal environments.

In a port context, drone imagery is processed through aerial triangulation and bundle block adjustment to generate georeferenced 3D point clouds. Vessels moored along quay walls are extracted from these point clouds and positioned relative to bollards along the quay wall, enabling the derivation of operational information such as berth occupancy, vessel extent and relative position along the quay. In a complementary maritime surveillance context, drone imagery can be used to detect vessels in open-water environments and estimate their position through direct georeferencing. Image observations are projected onto a sea-surface model using calibrated camera geometry together with GNSS/IMU-derived position and orientation information, avoiding the need for a full 3D photogrammetric reconstruction. Depending on payload and mission setup, additional information such as vessel dimensions, identity markings and inspection-relevant visual features can also be extracted.

The framework has been explored through case studies covering port operations and coastal/offshore surveillance. Results demonstrate centimetre-level geometric accuracy for photogrammetric reconstruction in port environments and vessel localization accuracies on the order of tens of metres in open-water surveillance scenarios. The work also highlights practical constraints for operational deployment, including flight geometry, image quality, camera calibration, payload configuration, automation level and integration with AIS-based vessel information and port digital twin environments.

By combining photogrammetric reconstruction, direct georeferencing, AI-based image interpretation and geospatial analysis, the framework demonstrates the potential of drones as operational decision-support tools for maritime stakeholders.

Extracting Cadastral-Scale Building Footprints from UAV-LiDAR Point Clouds in Rural Environments

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Extracting building footprints from UAV-LiDAR point clouds is vital for 2D/2.5D urban and rural mapping. We propose an end-to-end workflow integrating point-level classification, geometric instance extraction, concave hull vectorization, and independent cadastral validation. The approach was evaluated on a high-density (~3 cm spacing) dataset of 12 million points acquired over Pınarkaya, a rural settlement in Yozgat, Türkiye, utilizing 12% (1.45 million points) for training.

Points were classified into four categories (building, tree, wall, wire) using XGBoost. To prevent spatial data leakage, a 15×15 m spatial block cross-validation scheme across five folds was implemented, yielding an average cross-validation macro-F1 of 0.9675 (OA = 0.9869). On the regional validation set, the model achieved a macro-F1 of 0.9045. Walls exhibited the lowest performance (F1 = 0.69), with error rates reaching 46–88% below a 2 m height compared to 1.5–10% for buildings, reflecting geometric complexity and training sample constraints.

Classified building points were decomposed into roof and facade components to extract 22 building instances, vectorized using concave hull sectioning, and validated against 20 cadastral ground-truth buildings. Object-level matching yielded 16 true positives, 4 false negatives, and 6 false positives (completeness = 0.80, correctness = 0.73, F1 = 0.76). Matched pairs achieved a mean Intersection over Union (IoU) of 0.81, a median centroid offset of 0.31 m, and a pixel-level overall accuracy of 0.97 (F1 = 0.81). These findings demonstrate that high point-level classification accuracy reliably enables cadastral-scale footprint extraction in complex rural settings.

Developing Skills for Innovative Air Mobility: The Spanish CoVE Roadmap within the AIRMOB European Transformation Framework

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The rapid growth of Unmanned Aircraft Systems (UAS) operations in Spain, with an increase of more than 1,600% between 2019 and 2024, is accelerating the transition toward Innovative Air Mobility (IAM) and creating new workforce requirements across the aviation ecosystem. To support this transition, the AIRMOB project, co-funded by the European Union through the Erasmus+ Programme (Project No. 101194074), has established a network of Centres of Vocational Excellence (CoVEs) aimed at strengthening education, training, and skills development for the emerging IAM sector. Within this framework, the Spanish CoVE developed a national IAM Roadmap based on ecosystem analyses, stakeholder interviews, surveys, and collaborative workshops.

The roadmap identifies Spain's key strengths, including strong institutional commitment, advanced regulatory readiness, active participation in flight demonstrations, and a well-established collaboration network involving authorities, industry, academia, and air navigation stakeholders. At the same time, significant challenges remain, particularly regarding U-space deployment, certification processes, vertiport infrastructure, and the availability of qualified professionals.

To address these challenges, three strategic priorities are proposed: developing deployment-oriented training programmes aligned with operational needs, strengthening IAM competencies within public authorities, and anticipating future regulatory and certification skills requirements. The roadmap promotes modular lifelong-learning pathways, hands-on training linked to real use cases, stronger academia-industry collaboration, and the use of innovative digital learning tools. These actions aim to ensure a skilled, future-ready workforce capable of enabling the safe, scalable, and socially accepted deployment of IAM in Spain.

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S8. Emerging Applications of Drones

Drone-Enabled Transport of Intraoperative Onco-Surgical Specimens for Frozen Section Analysis: A Proof-of-Concept Study from India

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Background: Peripheral hospitals often lack facilities for intraoperative frozen section analysis, requiring onco-surgical specimens to be transported to tertiary pathology centres. Conventional road transport can delay diagnosis, prolong operative time, increase repeat surgeries, and adversely affect patient outcomes. This proof-of-concept study evaluated the feasibility, safety, and clinical utility of drone-enabled transportation of intraoperative onco-surgical specimens for frozen section diagnosis.

Methods: A prospective implementation study was conducted by the Indian Council of Medical Research (ICMR) in collaboration with Kasturba Medical College, Manipal, Dr. T.M.A. Pai Hospital, Karkala, and industry partners. The project was implemented in two phases. Phase I evaluated transportation of 14 non-oncological tissue specimens to assess specimen orientation, tissue integrity, cellular morphology, and evidence of autolysis following drone transport. Phase II involved transportation of eight intraoperative onco-surgical specimens requiring frozen section analysis for real-time surgical decision-making. In parallel, a TELOSS (Technical, Economic, Legal, Operational, Social, and Schedule) framework was applied to assess implementation feasibility and identify the most appropriate deployment strategy.

Results: All transported specimens-maintained orientation, tissue integrity, and histo-morphological characteristics without evidence of autolysis or cytoplasmic/nuclear degradation. Frozen section diagnoses were concordant with final histopathological findings in all clinical cases, enabling immediate intraoperative decision-making. Drone-assisted logistics supported breast-conserving procedures, confirmed tumour-free surgical margins in oral cancer surgery, guided management of ovarian malignancy, and prevented unnecessary radical procedures in benign lesions. TELOSS analysis identified a hybrid model employing drone transport for time-critical specimens as the most practical implementation strategy, balancing technical feasibility, operational efficiency, regulatory compliance, and cost-effectiveness.

Conclusions: Drone-enabled transportation of intraoperative surgical specimens is feasible, safe, and capable of preserving diagnostic quality while facilitating timely frozen section analysis. The approach has the potential to decentralize specialist pathology services, reduce repeat surgeries, optimize operating room efficiency, and improve access to advanced cancer care in geographically underserved regions.

Using an AI-Powered Decision Support Algorithm for Underground Monitoring with UAV-Integrated GPR

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Accurate, rapid, and reliable identification of subsurface structures and anomalies is crucial for infrastructure management, engineering projects, disaster response, archaeological research, and geotechnical investigations. However, traditional ground-penetrating radar (GPR) analysis primarily relies on expert experience, making the process time-consuming and subject to user variability.
This study presents an AI-driven decision support system developed through a university–industry partnership. It automatically analyzes data from a GPR system mounted on an unmanned aerial vehicle (UAV). The system transmits GPR data collected via the UAV to dedicated software, which conducts a multi-stage analysis using AI-supported algorithms developed as part of ongoing research.

The algorithm offers an integrated decision-making tool that not only processes radar images but also performs data quality control, detects subsurface anomalies, interprets potential structures, evaluates technical feasibility for the scenario, and automatically generates reports—all without user input. A key feature is its modular design, allowing easy adaptation across various sectors and applications. Consequently, it can produce scenario-specific reports for infrastructure detection, geotechnical surveys, archaeology, post-disaster assessments, engineering, and more.

This study details the system architecture, explains the core operation of the AI-assisted decision mechanism, and shares example analysis results from diverse fields. By showcasing automatically generated reports across different scenarios, the software demonstrates that it is versatile, scalable, and suitable for multiple disciplines. This approach aims to reduce reliance on experts, accelerate analysis, and ensure consistent decision support outputs across applications.

Multi-Temporal UAV Monitoring of the Rutor Glacier: Five Years of High-Resolution Change Analysis

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Climate change is strongly impacting the Alpine environment, increasing hazardous phenomena and rapidly changing this sensitive landscape. Repeated monitoring helps to understand the evolution of the lower part of the glacier, water dynamics, and geomorphological changes. For these reasons, Unmanned Aerial Vehicles (UAVs) are reliable tools for investigating small-scale evolution in complex environments.

This work presents the results of a five-year monitoring program carried out by the Geomatics GlacierLab research group of Politecnico di Torino on the Rutor Glacier, located in the Graian Alps (Aosta Valley, Italy), where UAV photogrammetric surveys were conducted every summer from 2021 to 2025. Several logistical challenges had to be overcome due to the limited battery endurance of the UAVs, weather conditions, and the fact that the study area is accessible only on foot. Over the years, several survey campaigns were carried out using DJI Phantom 4 to establish and survey a network of Ground Control Points (GCPs) and Check Points (CPs) supporting the drone flights. Furthermore, the lack of mobile network coverage required the use of a local DJI D-RTK 2 Mobile Station to provide RTK corrections during the field surveys.

The data processing workflow allowed the generation of high-resolution orthophotos and Digital Surface Models (DSMs), enabling comparisons between successive years. The adoption of a consistent acquisition and processing workflow ensured the reliability and comparability of the multi-temporal analysis. These products make it possible to quantify glacier surface elevation changes, estimate ice volume loss, and analyse frontal retreat.

The results highlight the importance of systematic UAV monitoring for supporting long-term glacier change assessment and the analysis of geomorphological modifications while providing valuable information to support the activities of the Regional Environmental Protection Agency (ARPA).

AIRMOB Spanish Cluster: Shaping IAM Education to Europe and Spain

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Innovative Air Mobility (IAM) is emerging as a transformative component of transport systems, integrating advanced aerial platforms, digital airspace management, and sustainable mobility solutions. Encompassing unmanned aircraft systems (UAS) and electric vertical take-off and landing aircraft (eVTOLs), IAM aims to optimize cargo transport, emergency services, asset monitoring, and passenger mobility.

As part of the AIRMOB project (Project No. 101194074), a project co-funded by the European Union through the Erasmus+ Programme, roadmap for education, this paper reviews key technological, infrastructural, regulatory, and educational challenges associated with European IAM deployment. Furthermore, the paper analyzes international implementation cases alongside the Spanish context, detailing regional initiatives and regulatory progress in metropolitan areas like Madrid. Special emphasis is placed on public-interest applications—medical logistics, emergency response, and environmental monitoring—expected to pioneer operations.

The study highlights the **Spanish AIRMOB Cluster**, operating as a regional Centre of Vocational Excellence (CoVE). By bridging gaps between industry, academia, and Vocational Education and Training (VET) providers, the Spanish cluster addresses local skill deficits in autonomous flight, UTM, and green aviation, ensuring workforce readiness aligns with evolving European frameworks.

Findings indicate that successful IAM adoption requires coordinated action among regulators, educational institutions, industry, and public authorities to guarantee safety, sustainability, interoperability, and public acceptance while building a skilled future workforce. And this paper presents Spanish AIRMOB Cluster as a body that could be the necessary link between the different interested stakeholders, promoting the adoption of IAM within the region.

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Abstracts — Posters

Poster Session A

A01. From Ecosystem Gaps to a Future-Ready Workforce: Mapping the Spanish IAM Skills Transformation

Francisco Pérez Moreno[1*], Rodrigo Hernán Gómez[2], Luis Moreno Santana[3], Esther Nistal Cabañas[4], Ángel Villalba Jiménez[5], Lidia García Barrero[6]

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The integration of Unmanned Aircraft Systems (UAS), U-space services, and future electric vertical take-off and landing (eVTOL) operations is transforming the Spanish aviation ecosystem and generating new requirements for technical, operational, regulatory, and institutional skills. While Spain has established a favourable environment for innovation through demonstrations, public initiatives, and stakeholder collaboration, the development of clear education and training pathways remains essential to support safe and scalable implementation.

Within the AIRMOB project, a project co-funded by the European Union through the Erasmus+ Programme (Project No. 101194074), the Spanish Centre of Vocational Excellence (CoVE) analysed these challenges through ecosystem assessments, stakeholder consultations, and surveys involving industry, education providers, students, and public institutions. This poster presents the resulting Spanish IAM Skills Roadmap as a structured pathway linking the current IAM ecosystem, identified skills gaps, strategic priorities, educational actions, and the future workforce.

The analysis identified several barriers to workforce readiness, including the limited availability of IAM-specific programmes, insufficient exposure to operational environments, gaps in knowledge related to U-space, eVTOL technologies and regulation, limited opportunities for upskilling and reskilling, and fragmented cooperation between education and industry.

To address these challenges, the Spanish CoVE defined three priorities: aligning training with current and future IAM operations, strengthening the capabilities of public authorities and regulators, and anticipating future regulatory and operational competence needs. Recommended actions include modular curricula, lifelong learning opportunities, simulation-based training, practical case studies, and collaboration with industry partners.

The roadmap provides a framework to translate ecosystem needs into educational actions, supporting the development of a skilled and future-ready Spanish IAM workforce while contributing to the wider AIRMOB European Transformation Roadmap.

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A02. IAM in Spain: An Overview Through Spanish AIRMOB Cluster's Eyes

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Innovative Air Mobility (IAM) is transforming transportation by integrating Unmanned Aircraft Systems (UAS), electric Vertical Take-Off and Landing (eVTOL) platforms, and digital airspace management into urban and regional environments. This poster provides a synoptic overview of IAM's scope—ranging from cargo logistics, emergency services, and asset monitoring to future air taxi operations—analyzing implementation trends globally and across Spain.

Within this framework, the poster highlights the **AIRMOB Project** (*Developing Skills and Capabilities for Innovative Air Mobility*, Project No. 101194074), co-funded by the European Union's Erasmus+ Programme. Special emphasis is placed on the **Spanish AIRMOB Cluster**, operating as a regional Centre of Vocational Excellence (CoVE). By bridging academia, Vocational Education and Training (VET) providers, regulators, and industry, the Spanish cluster addresses critical workforce skill gaps in autonomous navigation, U-space services, and green aviation, co-designing tailored training programs to accelerate safe, sustainable IAM adoption. Particularly, the study highlights the **Spanish AIRMOB Cluster**, operating as a regional Centre of Vocational Excellence (CoVE). By bridging gaps between industry, academia, and Vocational Education and Training (VET) providers, the Spanish cluster addresses the regional IAM situation, different initiatives and regional stakeholders. And, furthermore, it identifies skill gaps that AIRMOB will try to reduce as part of the roadmap pitch of the project.

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A03. Future-Resilient UAV Payload Modules: Deriving Design Requirements Based on a Structured Market Analysis

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The growing availability of mature Unmanned Aerial Systems (UASs) places payload modules at the center of mission-specific functionality. As UASs are increasingly deployed across diverse application domains, modular payloads enable rapid adaptation to changing mission requirements while improving operational flexibility and efficiency. While existing research predominantly focuses on UAS platforms and flight planning, payload is often proposed with very specific and, thus, limited use cases. There is a lack of a structured and scientifically grounded understanding of the overall payload landscape and its mapping to modular system architecture design. In particular, there is no comprehensive framework that systematically combines insights from the scientific literature with commercially available payload solutions and derives implications for the design of future payload systems.

This paper addresses this research gap through a structured research approach that combines systematic literature analysis with market analysis. First, the state of the art on UAS payloads is synthesized from the scientific literature to identify existing payload categories, functional capabilities, technological characteristics, and architectural concepts. In parallel, commercially available payload modules are analyzed and classified according to functional, technological, and application-specific dimensions. The findings from both analyses are then consolidated into a unified taxonomy of UAV payload modules, which forms the basis for identifying common design characteristics and deriving requirements for future payload systems.

Building upon this consolidated knowledge base, the paper derives design requirements for future-resilient payload modules by synthesizing recurring characteristics identified in both the scientific literature and existing industrial solutions. Particular emphasis is placed on modularity, interoperability, adaptability, scalability, and standardized interfaces to support flexible deployment across evolving mission requirements. Based on these requirements, architectural design principles for modular payload systems, standardized payload interfaces and compatibility between payload modules and carrier platforms are derived, enabling payload architectures that remain applicable across changing operational environments and disaster response scenarios.

A04. Deep Learning-Based Detection of Paint Peeling: An Evaluation of CNN Architectures for Automated Building Inspections

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Building facades are exposed to environmental and anthropogenic agents that accelerate degradation and compromise performance, durability, and service life. Paint peeling is a recurrent defect associated with loss of coating adhesion, moisture, material aging, and inadequate maintenance. This study evaluated convolutional neural networks for automatic paint-peeling detection on building facades. The dataset comprised 8,400 manually annotated image patches (448 × 448 pixels), predominantly from author-acquired images. Most source images were captured manually with a handheld RGB camera, while a smaller complementary portion was acquired using a DJI Air 2S UAV equipped with an RGB camera at variable distances of up to 5 m from the facades. Because manual acquisition predominated and capture distances varied, the dataset lacks a uniform flight-height range or spatial resolution. As standardized augmentation, each image and its annotations were rotated about the image center by 0°, 90°, 180°, and 270°. The dataset was divided into training, validation, and test subsets at a 70:20:10 ratio. Images were resized to 640 × 640 pixels during training and inference. Pre-trained YOLOv3, YOLOv5, YOLOv8, YOLOv12, Faster R-CNN, RetinaNet, and Cascade R-CNN models were retrained through transfer learning and fine-tuning. No systematic hyperparameter optimization was performed; predefined settings and implementation-default hyperparameters were used. A maximum of 150 epochs was established. YOLO models used native early stopping, whereas the remaining models were manually stopped based on learning-curve stagnation or overfitting. Test performance was assessed using Precision, Recall, mAP50, and mAP50–95. Except for Faster R-CNN, all architectures showed potential. YOLOv12 achieved the best metric balance, with an mAP50 of 0.820 and mAP50–95 of 0.630, while YOLO models offered a favorable trade-off between performance and training efficiency. Limitations included undetected early-stage peeling and scale effects: broader views favored advanced defects while masking smaller manifestations. Overall, YOLO architectures are promising for facade inspection.

A05. Archeological Mapping with Remotely Piloted Aircraft - Acquisition of Large-Scale Features

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The digital processing of aerial survey images, specifically using remotely piloted aircraft (RPA), offers great potential for mapping archaeological sites with inscriptions, whether paintings or petroglyphs. Mapping these environments requires sub-centimeter detail, accommodates geometric diversity, and is highly vulnerable. The Bisnau Archaeological Site is located in Formosa, Goiás. The data were obtained using a Mavic Pro and an RTK geodetic receiver. 11 support points were implemented: 6 GCPs (Ground Control Points) and 5 CPs (Check Points). The GCPs were randomly placed along the edge of the archaeological panel surface, with one used as a takeoff point, and the CP points were identified internally based on the petroglyph inscriptions. For photogrammetric processing, the software PIX4D and Orfeo were used, and to support the vectorization of the petroglyphs, a digital terrain model was generated. We interpreted the mapped petroglyphs and compared them with a planimetric topographic map from the Brazilian Cartographic System and Stellarium, which we used to compare solar movement with the apparent alignment of the petroglyphs. This application allowed us to observe that the petroglyphs are aligned with the apparent solar movement from the summer solstice for the year 5,650 B.C. Comparing the topographic map of the Bisnau region with the geometries of the petroglyphs demonstrated evidence that primitive peoples used petroglyphs for cartographic orientation. The results showed strong geometric similarity with the region's cartographic features. The results showed ARP's strong capacity to map archaeological environments. Using GeoPEC, the planimetric data were classified under the Cartographic Accuracy Standard-A at a scale of 1:1000, and they are more than sufficient to represent the petroglyphs geometrically.

A06. Fast Scattering Prediction for Deformed Metasurfaces Using a Fourier-Encoded Neural Surrogate

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6G networks are expected to use the upper mid-band (FR3, 7–24 GHz), where higher path loss and blockage by buildings become significant limitations, leaving drones in urban airspace with an intermittent link to ground infrastructure. Metasurfaces offer a low-cost way to restore coverage by redirecting the incident wave, but the panels deform under thermal and mechanical loading. Structural simulation predicts 0.55 mm of deformation under a worst-case thermal assumption, at which the scattering cross-section changes by up to 1.3 dB across the observation angles; at 5 mm the median change reaches 3.1 dB with a beam shift of up to 1.4°. Predicting this requires a full-wave solve for the surface current, taking 10 s to 9735 s across the parameter grid, followed by 6.2 s of radiation integration per scattering pattern.

This work presents a neural surrogate mapping the deformation state, incidence and observation angles, and frequency onto the bistatic scattering cross-section, with the deformation parameterized by analytical modal shape functions verified against structural finite element simulations. The oscillatory inputs are expanded onto a Fourier basis, and the contribution lies in how the bandwidth of that basis is set: rather than being tuned as a hyper-parameter, the angular order is taken from the Fourier spectrum of the response ($K = 60$) and the frequency order from the Nyquist limit of the 26 frequency samples ($K_f = 13$). A grid search over K required four training runs, about 78 minutes, to locate the value that a single fast Fourier transform (FFT) identifies in 0.02 ms. Trained on 3494 curves, the surrogate reproduces the full lobe structure to within 0.42 dB and evaluates a complete 401-point pattern in 7.25 ms (median of 1000 runs), about 850 times faster than the 6.2 s required for the radiation integral alone.

A07. Monitoring Temporal Changes in Fluvial Land Cover Using Deep Learning and Ultra-High-Resolution Drone Imagery

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Accurate monitoring of fluvial land cover is essential for understanding river dynamics and assessing flood-induced geomorphological changes. This study investigated temporal changes in fluvial land cover using ultra-high-resolution drone imagery and a deep learning approach. The drone images were acquired from 51 river reaches along the Kinu River in Japan between 2015 and 2019. RGB orthomosaic images were generated from aerial photographs using Structure-from-Motion (SfM) photogrammetry, providing a spatial resolution of approximately 4 cm per pixel. The deep learning method employed was the CNN-Supervised Classification framework (Miyamoto and Ishii, 2023; Carbonneau et al., 2020), which incorporates a two-stage convolutional neural network. Seven land cover classes were identified: gravel, sand, tree, grass, farmland, water surface, and artificial land. The trained model performed pixel-based classification of RGB orthomosaic images, achieving a weighted-average F-measure exceeding 90%, demonstrating that deep learning can accurately classify detailed fluvial land cover at ultra-high spatial resolution. Application of the trained model to the Kinu River imagery successfully revealed temporal changes in both fluvial land cover and geomorphological features, including stream channels, gravel bars, sandbars, and riparian vegetation. In particular, the analysis clearly captured significant landscape changes associated with the severe 2019 flood event, quantitatively identifying abrupt channel migration and extensive vegetation loss. These results demonstrate that combining deep learning with ultra-high-resolution drone imagery provides an effective framework for detailed riverine land cover mapping and quantitative assessment of geomorphological change. The proposed approach offers a practical tool for rapid post-flood damage assessment and supports long-term, large-scale monitoring of river environments, contributing to more efficient river management and conservation.

A08. Spatiotemporal Scene Graph for Scene-State Reasoning under Incomplete Observations in Repeated UAV Patrols

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Unmanned aerial vehicles (UAVs) are increasingly used as mobile sensing platforms for surveillance, inspection, monitoring, and situational awareness in large outdoor environments. However, repeated patrols rarely observe the same physical space under identical conditions, due to variations in flight position, camera viewpoint, field of view, and resolution, as well as occlusion. A missed detection therefore does not necessarily indicate the absence of an object, and associating objects across patrols is unreliable when objects move or their appearance changes. These limitations hinder consistent reasoning about scene states over time. We propose a spatiotemporal scene graph that accumulates incomplete observations from repeated UAV patrols. Observations are georeferenced to fixed spatial units using UAV positioning, depth, and visual cues, so that observations referring to the same physical space can be associated. Individual object observations are then matched across patrols based on spatial and visual consistency. Each spatial unit records observed objects, timestamps, positions, attributes, uncertainty, and mobility characteristics, and maintains one of three scene states: present, absent, or unobserved. When a unit's scene state is uncertain or its observations are insufficient, active re-observation is performed using an alternative position, viewpoint, or zoom level, driven by scene-state uncertainty rather than detector confidence alone. Based on these accumulated observations, a large language model (LLM) interprets user queries about the observed environment by retrieving spatiotemporal evidence from the scene graph together with semantic concepts and relations from an ontology-based knowledge graph. These sources are jointly used to interpret queried entities and events and to perform spatiotemporal reasoning. The framework is implemented in Isaac Sim and validated through experiments on spatial association, scene-state estimation, spatiotemporal query accuracy, and active re-observation under repeated patrols with varying UAV positions and viewpoints.

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A09. UAV multispectral validation of Sentinel-2 super-resolution toward a scalable observatory of the invasive seaweed *Rugulopteryx okamurae*

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The brown seaweed *Rugulopteryx okamurae* is an aggressive invader of the Strait of Gibraltar and the Gulf of Cádiz (SW Spain), forming massive intertidal strandings whose management requires frequent, large-area observation. Coupling UAVs with satellite super-resolution could enable operational, low-cost monitoring, yet the reliability of super-resolved imagery over dynamic coastal habitats has not been thoroughly evaluated. Using UAV multispectral orthomosaics (DJI Mavic 3 Multispectral, ~5 cm) as a high-resolution reference dataset, we assessed two Sentinel-2 super-resolution products, S2DR3 (1 m) and SEN2SR (2.5 m), over an urban beach affected by *R. okamurae*-dominated strandings in the city of Cádiz. Three UAV flights spanning about two hours sampled different water levels and illumination conditions during the same tidal cycle and were compared pixel-by-pixel across spectral bands and the Normalized Difference Vegetation Index (NDVI). Over exposed seaweed, the 1 m product (S2DR3) matched drone reflectance and NDVI far better than the 10 m and 2.5 m products (NDVI RMSE 0.09 vs 0.20 and 0.28), capturing the seaweed signature at metre scale and enabling finer delineation of strandings. The UAV series further showed that acquisition conditions strongly influence the signal: the NDVI of the same patch varied by about 0.14 across tide and illumination states, highlighting tide-synchronised, low-tide imaging as a key requirement for reliable tracking. Moreover, drone validation revealed a radiometric anomaly in one band of one product, which would have remained undetected without the UAV reference data. These results show that UAVs are critical for validating satellite super-resolution, and that super-resolved Sentinel-2 acquired at low tide can provide the foundation for a scalable, metre-scale observatory of *R. okamurae* strandings along the Andalusian coast.

A10. Behavioral Responses and Adaptation of Cattle Exposed to Uncrewed Aerial Vehicles

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Uncrewed aerial vehicles (UAVs) have become increasingly widespread in agriculture over the past few years, particularly in crop protection, and more recently in livestock production. However, practical information remains limited regarding how UAV operational parameters influence cattle behavior and how animals respond to repeated UAV exposure. Establishing flight conditions that enable effective observation while minimizing disturbance is therefore important for the animal-welfare-oriented implementation of UAV-based herd monitoring. The aim of this study was to investigate the behavioral responses and stress reactions of cattle under different drone flight parameters (flight altitude and speed) and to evaluate habituation to repeated UAV overflights.

Two DJI Mavic 3T drones were used to collect photographic and video recordings of cattle behaviour. Observations were conducted in three experimental groups, each consisting of at least 10 animals. Behavioral changes were assessed using a visual behavior-scoring system.

Higher flight altitudes (>30 m AGL) combined with lower flight speed (3 m/s) elicited lower responses while still providing sufficient resolution for effective animal observation. In the case of repeated flights, significant habituation was observed in all groups exposed to overflights over time. Some differences were observed between different breeds, while there was no significant difference in the case of age and sex.

The results of this study contribute to the development of cattle-adapted UAV operating protocols and best management practices (BMPs), supporting the safe, effective, and animal-welfare-oriented application of drone-based herd monitoring.

A11. A Comparative Analysis of the Rangeland Analysis Platform and Drone Imagery for Woody Cover in Texas, USA

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Geospatial technologies have become essential to assess ecological processes, quantify changes in land use, and monitor vegetation dynamics in rangelands. The integration of remote sensing and field-based data collection has led to the development of online platforms that use remote sensing to estimate vegetation cover, forage production, and biomass. One of the most popular platforms in the United States is the Rangeland Analysis Platform (RAP). While RAP provides biomass and cover estimates across the United States, spatial resolution may limit the accuracy of fractional cover. Drones have been successfully used to estimate biomass and vegetation cover at fine scales. As concerns about woody plant encroachment grow, these technologies offer new opportunities to quantify both the amount and spatial distribution of vegetation cover. Therefore, the goal of this study was to evaluate the correspondence between RAP estimates and drone imagery data for woody cover. We used data from the state of Texas, due to the diversity in vegetation communities and geographies. We used drone-based imagery at multiple sites with the image resolution at less than 2cm and flight area ranging from around 30 to 120 ha. We conducted the classification, confusion matrix, and accuracy assessment in ArcGIS Pro, and we made the comparison of drone imagery to RAP woody cover estimates using multiple focal windows sizes (3 x3, 5x5, 7x7, and 9 x9). In our initial results, the accuracy of our woody cover classifications from drone imagery ranges from 87 to 90 percent. We hypothesize that estimates from RAP and drone imagery will differ in woody cover correspondence depending on woody cover spatial configuration and focal window size.

A12. Quantifying phenological changes and invasions of *Rosa bracteata* cover on Southeast Texas rangelands

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Invasive plants can dominate rangelands by displacing native species critical to ecosystem functioning. Quantifying the amount and configuration of invasives at very-fine spatial resolutions enables efficient monitoring and control. Advances in drone technology for “on-demand” imagery provide new opportunities to assess changes in vegetation cover. The objectives of this study are to (1) assess seasonal differences in quantifying the cover configuration of *Rosa bracteata* and (2) analyze temporal changes in *R. bracteata* cover between two years to quantify spread. We collected quarterly drone imagery on a ranch in southeastern Texas (29°55'53.5"N 95°50'54.0"W) from December 2023 to June 2025. We classified *R. bracteata* using an object-based image classification and computed patch metrics including area (AREA), shape index (SHAPE), and Euclidean nearest neighbor distance (ENN). We evaluated seasonal effects due to plant phenology on image classifications by comparing different seasons within the same year (2024 and 2025) using Kolmogorov-smirnov ($P < 0.05$) tests. To quantify cover change, we compared classified *R. bracteata* imagery from March 2024 to March 2025. The average overall accuracy for all image classifications was 90.7%, while the average producer’s and user’s accuracy for *R. bracteata* were 90.4% and 90.2% respectively. In 2024, AREA, SHAPE, and ENN showed statistically similar values for December, March and July, and statistically different values for September. In 2025, AREA, SHAPE, and ENN values were statistically similar for February, March, and June. This suggests that time of year may affect the quantification of *R. bracteata* in late growing seasons. Overall, the net change in *R. bracteata* cover for one year was a gain of 5.9%. Given this level of rapid spread, developing strategies to quantify the configuration and spread of invasives at very-fine scales can improve our ability to selectively treat patches and monitor growth to improve ecosystem health.

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A13. Predictive performance of a machine learning model for plot-level dry matter yield estimation using drone derived multispectral indices.

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Accurate and non-destructive herbage mass estimation has significant potential for both commercial farm management and research applications. High resolution drone imagery can potentially provide an avenue to estimate herbage yield through the collection of multispectral data. However, optimising the use of multispectral vegetation indices remains a key challenge. This study evaluated the performance of an XGBoost gradient boosting framework incorporating multiple multispectral vegetation indices to predict plot-scale dry matter yield (kg DM/ha) in perennial ryegrass (*Lolium perenne* L.).

Imagery was captured across plot trials using a DJI Mavic 3M multispectral sensor. The following spectral vegetation indices were calculated from the imagery; Normalised Difference Vegetation Index (NDVI), Green Normalised Difference Vegetation Index (GNDVI), and Normalised Difference Vegetation Index Red-Edge (NDVIre), alongside actual measured plot level dry matter yield (kg DM/ha). An XGBoost regression model was trained using 5-fold cross-validation with early stopping. Feature importances were calculated using fractional gain.

The XGBoost model predicted plot dry matter yield with an R^2 of 0.48, and a Root Mean Square Error of 395.87 kg DM/ha. The trial accounted for significant baseline variation, while NDVI (Gain: 0.133) and NDVIre (Gain: 0.115) provided the highest relative predictive contribution among spectral features, outperforming GNDVI (Gain: 0.102).

Combining multispectral indices with gradient boosting provides a viable workflow for dry matter yield estimation, offering an efficient methodology for high-throughput assessment.

A14. High-Resolution Optical-Zoom Drone Imagery for the First Quantitative Estimate of *Euphorbia dendroides* in a Coastal Cliff Sector of Monte Conero

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Coastal cliffs remain among the least investigated terrestrial environments because steep slopes, instability and limited accessibility strongly constrain conventional vegetation surveys. As a consequence, ecologically and biogeographically relevant plant populations may be known only through presence records, with little quantitative information on their abundance and spatial distribution. This is the case of *Euphorbia dendroides* L. at Monte Conero, where the species occurs near the northern limit of its Adriatic distribution range on largely inaccessible calcareous cliffs.

This study provides the **first quantitative estimate of this population** by combining high-resolution optical-zoom drone imagery with a **two-phase sampling design** over a 23.78 ha coastal cliff sector. In the first phase, the area was divided into 25 × 25 m cells and screened to identify those potentially suitable for *E. dendroides*. In the second phase, sampling plots were selected within these cells to obtain a spatially distributed sample used for population estimation. Nadir images were acquired from 90 m using a **16× optical zoom (405 mm equivalent focal length)**, with a ground sampling distance of approximately **1 mm pixel.** Each analysed image represented 44.3 m^2, allowing individual plants to be visually identified and counted.

A total of 206 images covering 9,126 m^2 were analysed. *E. dendroides* was detected in 80 plots, with 420 individuals directly counted. Using the **two-phase sampling estimator**, the population within the entire study area was estimated at **9,154 individuals** (RSE = 14.9%; sampling error = ±1,364 individuals). Higher abundances occurred in the northern sector and closer to the coastline.

These results show that high-resolution optical-zoom drone imagery combined with targeted two-phase sampling enables **individual-based population estimates in steep and inaccessible environments**. The approach is repeatable, spatially explicit and potentially transferable to other plant species recognizable from high-resolution imagery, providing a flexible framework for biodiversity monitoring and future change detection.

A15. Application of UAS-Based RGB Imaging for High-Throughput Maize Plant Height Phenotyping

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UAS-derived RGB imagery offers a rapid, efficient, and non-invasive approach to high-throughput phenotyping, enabling cost-effective assessment of key agronomic traits in maize. During the 2025 growing season, a panel of 400 maize genotypes, comprising 200 hybrids and their respective parental components, was evaluated for plant height across two field locations in Serbia. RGB images were acquired weekly throughout the growing season, with acquisition frequency increased to twice weekly during pollination, using a DJI Mavic 3M UAS at a ground sampling distance (GSD) of 0.42–0.54 cm pixel^{-1}. RGB orthomosaics and digital elevation models (DEMs) were processed for plot-level data extraction, with plant height estimated using a surface differencing approach. A Digital Surface Model (DSM) derived from UAV imagery was differenced with a bare-soil DEM to generate Canopy Height Models (CHMs), from which mean, median, 95th percentile (P95), maximum height, and standard deviation were calculated for each plot. Regression analysis revealed nonlinear temporal dynamics in maize height development, with the cubic model providing the best fit (R^2 = 0.885), compared with quadratic (R^2 = 0.869) and linear models (R^2 = 0.729). Across both environments, UAV-derived maximum canopy height showed the strongest correlation with manually measured plant height (r = 0.594 and 0.509; $p < 0.001$), whereas mean and median canopy height metrics showed weaker and less consistent associations. These findings indicate that maximum canopy height is the most informative UAV-derived metric for estimating maize plant height. Future work will focus on improving DSM normalization and ground-surface estimation, minimizing canopy occlusion and plot-edge effects, and enhancing the robustness and stability of UAV-derived height metrics across growth stages and varying canopy densities.

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A16. Water Spray Efficiency of UAV-Scale Aerial Firefighting under Crosswind Conditions: An FDS-Based Dimensionless Analysis for Operational Design

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Wildfires increasingly threaten forests worldwide, and uncrewed aerial vehicles (UAVs) are emerging as valuable tools for early-stage suppression—especially in forestry and agricultural landscapes where rapid, targeted water delivery can stop a fire before it spreads. Yet how much water a firefighting drone truly needs remains poorly understood, because current planning relies on a fixed efficiency value (70%) borrowed from large-scale eucalyptus forest operations that was never validated for small drones operating in wind. This study uses high-resolution fire simulation to quantify how effectively water sprayed from a UAV reaches and cools a wildfire flame across a realistic range of wind conditions. Forty scenarios were examined, varying wind speed, spray release speed, and the timing of the water drop relative to the fire's growth. Wind emerged as the dominant factor governing effectiveness, with efficiency ranging widely from about 1.5% to 40%. A notable "sweet spot" was found at moderate wind (around 2 m/s), where rising heat and crosswind balance to keep water in contact with the flame longest; releasing water precisely as the fire peaks improved effectiveness by up to 50%. Overall, the conventional 70% assumption overestimates real drone performance by roughly three-and-a-half times. The study delivers practical, wind-adjusted guidance to help forestry and emergency-response teams plan drone water loads, laying a foundation for smarter autonomous aerial firefighting in vulnerable pine-forest regions such as Korea.

A17. Radiometric Correction of UAV Multispectral Imagery Under Variable Illumination Using a Single Calibrated Reflectance Panel

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UAV-based multispectral remote sensing is sensitive to illumination variability during image acquisition. Several studies argue that the automatic radiometric correction performed using manufacturer-supplied downwelling light sensors (DLSs) and a single calibration panel image is insufficient, recommending instead the deployment of multiple reference panels across the field. This study tested that recommendation by evaluating a simpler workflow relying solely on the standard calibration system, a single MicaSense Calibrated Reflectance Panel (CRP) imaged before and after each flight. Multispectral imagery was acquired with a DJI Mavic 3M over a 2.2 ha coffee field at Oasis Farm, Coimbra, Minas Gerais, Brazil, on three days with markedly different illumination: a clear, sunny day (July 7, 2026), a heavily overcast day (July 9, 2026), and a mixed day that began clear and grew increasingly cloudy (July 10, 2026). Flights were conducted at 100 m above ground level with 85% front and side overlap, and repeated at four course orientations (20°, 65°, 110°, and 155°), the first aligned with the dominant crop row direction, to evaluate possible interactions between flight-line geometry and illumination. Reflectance values in each spectral band, along with derived NDVI maps and the digital surface model (DSM), were compared across course angles and acquisition dates. Results showed nearly identical reflectance values, NDVI patterns, and DSMs regardless of course orientation or sky condition, indicating no meaningful radiometric inconsistency. These findings suggest that manufacturer-based radiometric calibration using a single CRP and the UAV DLS sensor is sufficient to obtain consistent, illumination-independent reflectance data, avoiding the added field logistics and image-processing complexity associated with installing multiple in-field calibration panels.

A18. Landscape-Level Forage Estimation Using Fine-Scale Drone Imagery in Rangelands

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Quantifying the amount and spatial distribution of forage mass is critical for managing and enhancing rangeland health and ecosystem services. Remote sensing allows for landscape-level estimations of forage mass, requiring less labor and time in the field than traditional vegetation collection. Our objective is to quantify forage mass and forage production at a fine scale over larger extents with drones and compare to field measurements. We evaluate the capacity of drones to provide improved forage mass estimations on an operational scale in the Southern Great Plains. To quantify forage mass, we collected 1.5 cm resolution Red–Green–Blue (RGB) drone imagery to generate a canopy height model (CHM) at a 7 cm resolution at three Texas, USA, locations throughout the growing season: Vernon (site 1: 94 ha, 678 mm average annual precipitation) and Sweetwater (site 2: 51 ha, site 3: 99 ha; 592 mm average annual precipitation). We collected 30 vegetation clippings per location per sampling event. Vegetation clippings were dried and weighed to estimate forage mass, then compared to forage volume estimated from the CHMs using linear regression. We also developed a framework for a supervised, object-based image classification, which was used to remove woody cover and provide an adjusted forage mass estimation. R^2 values ranged from 0.3585 to 0.6182 in site 1, from 0.6368 to 0.7844 in site 2, and from 0.3752 to 0.8065 in site 3. Overall accuracy of image classifications ranged from 85.6 to 99.9% for site 1; 95.9% to 99.5% for site 2; and 96.8% to 99.5% for site 3. We estimate total adjusted forage mass for each one of these sites. This work provides a framework for landscape-scale estimation of forage mass that can help livestock producers and land managers adjust stocking rates to maintain or improve rangeland health and wildlife habitat.

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Conner A Ties, Shanna R Gleason and Humberto L Perotto-Baldivieso; Writing - original draft, Mollie L Kemp and Humberto L Perotto-Baldivieso; Writing - review and editing, Mollie L Kemp, J. Silverio Avila-S., Sorin C Popescu, Andres Cibils, Conner A Ties, Shanna R Gleason, Nuria Gomez-Casanovas, William E Pinchak and Humberto L Perotto-Baldivieso; Supervision, J. Silverio Avila-S. and Humberto L Perotto-Baldivieso; Project administration, J. Silverio Avila-S. and Humberto L Perotto-Baldivieso; Funding acquisition, J. Silverio Avila-S. and Andres Cibils;

A19. Drone-Derived Vegetation Responses to a Rainfall Pulse in a Semi-Arid Rangeland

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In semi-arid rangelands, rainfall pulses drive vegetation growth. Understanding vegetation responses to rainfall is important for evaluating forage availability and ecosystem resilience. Traditional field methods provide valuable measurements but are often limited in capturing fine-scale changes at the landscape level. This study evaluates very high-resolution drone imagery to quantify herbaceous and woody vegetation responses following a rainfall event in South Texas, USA. Drone surveys were conducted two weeks before rainfall (March 12, 2025) and two and six weeks after the event (April 12, 2025 and May 12, 2025), generating approximately 5 cm orthomosaics and canopy height models to estimate vegetation volume across the study area. We collected field data to identify native and invasive grass communities. From this, we randomly selected 150 sample areas (3 m diameter) for each vegetation cover type from the imagery. We used the nonparametric Kruskal-Wallis test (alpha = 0.05) to evaluate differences in mean volume among sampling periods and the Kolmogorov-Smirnov test for pairwise comparisons among distributions of functional groups. Invasive and native vegetation did not differ significantly among sampling periods, whereas woody vegetation increased significantly from March (10,776,330 cm^3) to April (14,568,020 cm^3) and remained elevated through May ($P < 0.05$). Pairwise comparisons showed that woody vegetation differed significantly between March and April and between March and May (15,129,680 cm^3; $P < 0.05$), while no significant differences were observed between April and May or among sampling periods for herbaceous vegetation. The greater structural response observed in woody vegetation is consistent with previous research suggesting that growing-season rainfall, combined with access to deeper soil moisture through deep root systems, may support greater volume growth than in shallow-rooted herbaceous species. By integrating drone-derived imagery and traditional field methods, this approach captures fine-scale vegetation dynamics at the landscape level.

A20. Precision Irrigation 2.0: Intelligent Co-Design of Drone Fleets and Soil Sensor Networks for Water-Efficient Agriculture

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Precision irrigation in center-pivot fields demands a critical yet unsolved challenge: simultaneously deciding where to place soil sensors, what technology to deploy, how many drones to operate, and how to route them—all while ensuring synchronized, real-time field snapshots within tight time windows. This work presents an innovative Decision Support System (DSS) that solves this coupled co-design problem by jointly optimizing sensor placement, multi-UAV routing, and fleet sizing under realistic electromagnetic communication constraints and agronomic synchrony requirements. Unlike sequential workflows that decouple these decisions and incur substantial sub-optimality penalties, our framework integrates three computational layers: (1) a mixed-integer linear program optimizing sensor placement and routing jointly; (2) an Adaptive Large Neighborhood Search heuristic with Hamiltonian lower-bound verification, ensuring fleet-size recommendations are certified within 0.19% of optimality; and (3) an economic layer comparing passive RFID tags (cheap but demanding larger drone fleets) against active LoRaWAN nodes (expensive but requiring fewer drones). Applied to a 241-cell center-pivot field, the DSS reveals that co-design value is regime-dependent—substantial under LoRaWAN—and identifies a critical sensor-density band (76–79 nodes) where the cost-optimal technology switches. The framework accommodates non-circular field geometries and demonstrates that enforcing spatial homogeneity reduces blind-spot radii by up to 9% at zero additional cost. Verified on real agronomic synchrony windows (15–30 minutes), this DSS empowers farm operators to make data-driven infrastructure decisions before deployment, balancing hardware investment against operational drone costs over multi-year farm lifecycles.

Author contributions: Conceptualization, Shira Zucker ; Visualization, Shira Zucker ; Project administration, Shira Zucker ; Funding acquisition, Shira Zucker ;

A21. UAV-Based Multispectral Imagery in Crop Breeding: Cicer Milkvetch Forage Yield Prediction as an Example

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Manual data collection in forage crop breeding is highly labor-intensive and becomes an operational bottleneck. Application of unmanned aerial vehicles (UAVs) offers a solution to modernize field data collection. This study evaluates the effectiveness of predicting individual plant biomass yield in cicer milkvetch (Astragalus cicer L.) from multispectral imagery from UAVs with field agronomic data. A space-planted nursery containing over 200 half-sib families, including commercial cultivars AC Oxley II and AC Veldt, was established in 2023 at the Livestock and Forage Centre of Excellence (LFCE) of the University of Saskatchewan near Saskatoon, SK, Canada. The experimental layout followed a randomized complete block design with three replications and a 1-meter plant spacing. UAV flights were conducted 3 times from 1 May through 30 June 2024 to collect vegetation indices, including the Normalized Difference Vegetation Index (NDVI) and Excess Green Index (ExG), and canopy area measurements. Forage dry matter yield (DMY), spring vigor score and plant height were utilized as ground-truth data to validate these UAV-derived datasets. A Random Forest (RF) model was used to predict DMY. Hyperparameter tuning significantly optimized model prediction, and increased the coefficient of determination from R^2 = 0.50 to R^2 = 0.71. Canopy area and vegetation indices (NDVI and ExG) collected immediately prior to biomass harvest were the most accurate indicators. In contrast, initial NDVI was insignificant in predicting DMY. These outcomes demonstrate that UAV-based phenotyping provided fast and acceptable predictive capabilities for forage crop breeding; however, the timing of flights seemed significant in improving predicting accuracy.

Author contributions: Conceptualization, Bill Biligetu; Methodology, Dashnyam Byambatseren; Software, Dashnyam Byambatseren; Validation, Dashnyam Byambatseren; Formal analysis, Dashnyam Byambatseren; Resources, Bill Biligetu; Data curation, Dashnyam Byambatseren; Writing - original draft, Dashnyam Byambatseren; Writing - review and editing, Bill Biligetu; Supervision, Bill Biligetu; Funding acquisition, Bill Biligetu;

A22. Towards an Interoperable Multi-Agency UAS Framework for Civil Protection Emergencies: Operational Experience from the Italian Competence Centres Network

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The increasing adoption of UAS in civil protection operations calls for operational frameworks capable of ensuring interoperability, standardization and effective coordination among organizations with different institutional mandates and technical expertise, that may operate simultaneously or jointly for specific needs. In Italy, this challenge is being addressed through the UAS Network of the Civil Protection Competence Centres, established in 2019 to foster cooperation among research centres, environmental agencies and academic institutions operating UAS capabilities in support of the disaster management cycle.

Rather than focusing solely on technology, the Network is developing a shared operational framework based on common procedures, coordinated activation mechanisms, harmonized operational standards, and interoperable information flows. Joint exercises constitute the primary mechanism for validating this framework through an incremental, application-oriented approach.
A series of increasingly complex national exercises drove progressive evolution. The 2023 seismic scenario tested the coordinated deployment of multiple UAS teams; the 2024 hydro-meteorological exercise tested a different multi-risk scenario; the 2025 county-scale exercise introduced more realistic blind-testing conditions to evaluate field performance and network coordination. The national-scale flood exercise EXE Po 2026 enabled, for the first time, the complete validation of the operational chain, from stakeholder requests to task assignment, airspace coordination through the Air Operations Coordination Centre, field operations, and output delivery. This represented a significant step towards integrating UAS capabilities into established civil protection command-and-control processes.

A key enabling component of this framework is the VEGA platform, which supports mission management, georeferenced data collection, operational communication, product sharing, and real-time situational awareness across all operating organizations.

The experience demonstrates that building a national multi-agency UAS framework is an iterative process driven by successive trials, lessons learned, and continuous refinement. While still under development, the approach provides a practical pathway towards standardized, interoperable, and scalable UAS operations capable of supporting complex civil protection emergencies.

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Author contributions: Conceptualization, Guglielmo Rossi; Methodology, chiara casarotti, Flavio Pignone, Martina Mandirola, Umberto Morra di Cella, Teresa Gracchi and ANDREA BERTON; Software, Guglielmo Rossi; Investigation, Flavio Pignone and Teresa Gracchi; Data curation, Martina Mandirola and ANDREA BERTON; Writing - original draft, chiara casarotti and Martina Mandirola; Writing - review and editing, chiara casarotti, Flavio Pignone, Umberto Morra di Cella, Guglielmo Rossi, Teresa Gracchi and ANDREA BERTON; Supervision, chiara casarotti and Umberto Morra di Cella; Funding acquisition, chiara casarotti, Umberto Morra di Cella and Guglielmo Rossi;

A23. Inference of Agronomic Information in Smallholder Systems from Low-Altitude UAV RGB Imagery

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Multispectral and hyperspectral drones provide rich agronomic information but remain costly for smallholder farming systems, where consumer RGB cameras are far more accessible. Yet, the extent to which simple RGB imagery can substitute for, or complement, more advanced sensing remains poorly quantified. This study evaluates that potential of cereal monitoring in Morocco, across four analytical axes: RGB spectral indices, GLCM texture, cross-modal Support Vector Regression (SVR) for continuous NDVI prediction, and Structure-from-Motion (SfM) crop-height estimation, complemented by altitude-robustness and sensor-sensitivity analyses. Multi-temporal data were acquired over wheat and barley at an experimental station (nine dates, 2024–2025), with a second site used for cross-site transfer testing. The Green Leaf Index tracked NDVI at r = 0.929 and detected senescence onset two to three weeks earlier. The SVR model predicted NDVI at R^2 = 0.933 under spatially independent (Spatial K-Fold) validation, with spectral and textural features contributing comparably. Object-based classification recovered 82% of the multispectral discrimination capacity. Spectral indices remained stable at altitudes from 10 to 90 m altitude, whereas texture varied with resolution. Critically, direct cross-site transfer failed (R^2 = -1.401); however, a two-parameter linear recalibration restored performance (R^2 = 0.576). Furthermore, simulated cross-sensor tests preserved spatial structure ($R^2 > 0.97$) while shifting absolute values by -6% to -17%. These convergent results reveal a general principle: RGB imagery preserves the relative geometry of agronomic information but not its absolute scale. Consumer RGB drones therefore offer a reliable, low-cost temporal monitoring tool that complements, rather than replaces, multispectral sensing, provided that per-site and persensor recalibration is applied.

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Author contributions: Conceptualization, Ali Elbattay, MOUANIS Lahlou and Aladine CHETOUANI; Methodology, Oussama Yasser BOUIH, Ali Elbattay and Aladine CHETOUANI; Software, Oussama Yasser BOUIH and Aladine CHETOUANI; Validation, Oussama Yasser BOUIH, Ali Elbattay, MOUANIS Lahlou and Aladine CHETOUANI; Formal analysis, Oussama Yasser BOUIH; Investigation, Oussama Yasser BOUIH; Resources, Ali Elbattay; Data curation, Oussama Yasser BOUIH; Writing - original draft, Oussama Yasser BOUIH; Writing - review and editing, Ali Elbattay, MOUANIS Lahlou and Aladine CHETOUANI; Visualization, Oussama Yasser BOUIH; Supervision, Ali Elbattay, MOUANIS Lahlou and Aladine CHETOUANI; Project administration, Ali Elbattay;

A24. Development of Safety Metrics for Urban Air Mobility Operations – The Case of People Transportation

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The Urban Air Mobility (UAM) concept has gained a lot of attention from aviation experts globally. While this UAM concept is forecast to materialise over the next decade, there are aspects that dictate immediate action. This research aims to propose a new safety management framework for the UAM operations of people transportation and package delivery. The main gap is the missing safety metrics from Unmanned Aircraft System (UAS) operation safety management. In this paper, Safety Performance Indicators (SPIs) are proposed. These safety metrics are customised for every phase of UAS flight. Six distinct flight phases are analysed and safety metrics are proposed for each. Moreover, another interesting finding is linked to the increased level of automation which will be required by these types of operations. Finally, the concept of a Total Safety Performance indicator is proposed, derived from certain individual Safety Performance indicators. This assures a minimum level of Safety Performance, taking into account not only the UAS and its operator but also the performance of the involved stakeholders.

Author contributions: Conceptualization, Michail Karyotakis; Methodology, Michail Karyotakis; Validation, Graham Braithwaite; Writing - original draft, Michail Karyotakis; Writing - review and editing, Michail Karyotakis;

A25. Drones vs. Satellites: A Comparative Analysis of Low- and High-Altitude Imagery in Cereal Crop Mapping

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The development of unmanned aerial vehicle (UAV) technology is significantly transforming crop management methods in precision agriculture, enabling high-resolution field mapping as well as the assessment of plants' physiological health and stress levels. The aim of the conducted research was to validate the Drought Monitoring System at the IUNG-PIB Agricultural Experimental Stations in terms of its effectiveness in detecting suboptimal crop conditions caused by agricultural drought.

Data acquisition was based on UAV flights performed at an altitude of 100 meters (AGL), utilizing a 7-sensor multispectral camera covering blue, green, red, Red Edge, near-infrared (NIR), long-wave infrared (LWIR), and panchromatic bands. The Normalized Difference Vegetation Index (NDVI) was primarily used for the quantitative and qualitative assessment of vegetation status.

The obtained high-resolution spectral imagery enabled a precise, non-destructive assessment of key agricultural crops, taking into account not only plant health status and fertilizer requirements but also the estimation of soil moisture and soil heterogeneity. It was demonstrated that UAV-based imagery allows for a more accurate delineation of drought-affected areas (including crop losses in triticale) compared to traditional in-situ measurements. A direct comparative analysis of satellite imagery from the Sentinel-2 system and drone imagery recorded on the same date revealed stark divergences in spectral reflectance resulting from the secondary growth of the oat crop. Furthermore, the collected data was used to map Land Surface Temperature (LST) for the purpose of calculating Potential Evapotranspiration (ETP), as well as to test machine learning algorithms to quantify the percentage cover of weeds (e.g., Apera spica-venti). The application of the NDVI index based on spectral data provides a reliable basis for monitoring dynamic changes in crops throughout the growing season.

Author: Tytus Berbeć (IUNG-PIB)

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Author contributions: Resources, Tytus Jan Berbec;

A26. Toward Decision-Conditioned Credibility for an Unvalidatable UAS Acoustic-Disturbance Digital Twin

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Small uncrewed aircraft systems (UASs) increasingly operate near noise-sensitive animals, and physics-based acoustic digital twins are now used to plan "wildlife-safe" flight altitudes and buffer distances. Such decision-support models face a structural obstacle: in situ validation against the sound pressure levels an animal actually perceives is rarely feasible, so operators are asked to trust a model that cannot be validated in the conventional sense. This work explores a question other than "is the model correct?": whether the operational decision the model informs actually depends on what remains unknown.

To address this, we are developing a reproducible, standards-grounded credibility-evaluation workflow for an unvalidatable UAS acoustic-disturbance twin (ISO 9613-2 propagation). The workflow combines solver verification, input-pedigree classification of aleatory and epistemic uncertainty, uncertainty quantification following GUM/JCGM 101 (Monte Carlo with a polynomial-chaos surrogate), and global sensitivity analysis (Morris screening to Sobol indices). Its central idea is decision-conditioned credibility: sensitivity and credibility are assessed against the decision indicator, whether the predicted level exceeds a species audiogram threshold, rather than the raw output distribution. This reframes an empty validation factor from a fatal gap into a testable question, and points toward a ranked, value-of-information measurement priority.
The approach is illustrated on a case study of multirotor operation near a sensitive terrestrial receptor (domestic-horse audiogram), with the aim of deriving a minimum trustworthy operating altitude and horizontal buffer under a bounded exceedance-probability constraint. The intended outcome is a transparent basis for trusting model-based operational limits when validation data cannot be obtained.

Poster Session B

B01. Application of RPA and AI in the Identification of Pests in Cotton Plantations in the Brazilian Cerrado

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Amaranthus palmeri is a weed in North America that significantly reduces productivity, grows rapidly (25–50mm/day), and produces approximately 500,000 seeds/plant. In Brazil, it was detected in Mato Grosso in 2015. It is now found in other states, threatening soybean and cotton crops. Conventional inspection cannot cover large areas. To address this challenge, the research focused on using RPA and AI to develop an "open source" platform to map, identify, and monitor crops. To obtain the data, a Matrice 350 – RTK, a DJI P1 aerial photogrammetry camera, and a GNSS DA 2 were used. Two data collection stages were carried out to monitor the phenological process. The images were pre-processed with the software "Metashape." The samples were used to train a neural network, and processing was carried out with the GeoLearning plugin; finally, testing and validation were conducted on areas not used for training to avoid bias in the results. For the final flight adjustments, several tests were conducted to obtain the best image, given weed size and possible mixing with other species. Among the Deep Learning architectures, YOLO 11 was used. GeoLearning was developed in three main modules: sample collection, training, application, and detection. The plugin was built in PyQt 5 and integrated into QGIS using GDAL, Ultralytics, and OpenCV. After developing and testing GeoLearning and collecting samples, the researchers trained the model on Google Colab. The performance metrics (precision—95%, recall—93%, and MAP @ 0.5—99%) showed that the model can reliably identify the target species and generate a final report that includes the identified elements with their respective coordinates.

B02. Bitemporal Integration of Spectral Indices Obtained from UAS–Sentinel-2 Images for the Estimation and Spatial Analysis of Maize Yield

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Yield estimation through remote sensing is a valuable tool to support agricultural decision-making; however, spatiotemporal canopy heterogeneity can limit model accuracy and affect statistical inference when spatial dependence exists. This study aimed to estimate maize (Zea mays L.) yield through vegetation indices obtained from Sentinel-2 images and unmanned aircraft systems (UAS), integrating information from two growing seasons with different agronomic management. This observational study included two maize genotypes, Maxeed and Darkness, and two preceding crops: maize and sugar beet. Because the original yield was assigned at a spatial scale larger than the sampling units, several observations had identical values, preventing adequate representation of point-to-point spatial variability. To address this limitation, a partial least squares regression model was fitted using vegetation indices derived from 2023 satellite images and from 2024 satellite and UAS images, considering only the R1 reproductive phenological stage. The final model retained five indices, highlighting the UAS-derived Normalized Difference Vegetation Index for the current growing season and the satellite-derived Advanced Vegetation Index for the previous growing season. Subsequently, a spatial analysis of variance with a selective spatial lag term was applied to the estimated yield. Maxeed presented a higher mean yield than Darkness (12,488 kg/ha versus 10,831 kg/ha; approximately 15% higher), with statistical evidence of differences between genotypes. Incorporating the spatial component eliminated the residual autocorrelation initially detected. The methodology integrated two technologies and two growing seasons to compare genotypes under different preceding crops. The estimated yield was higher when the preceding crop was sugar beet, with increases of 21.7% for Maxeed and 4.6% for Darkness compared with conditions preceded by maize.

B03. Definition of U-Plan 4D Volumes and Their Impact on Flight Authorisation and Airspace Capacity

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Unmanned Aerial System (UAS) traffic management (UTM) environments, including the European U-space, are designed to enable the safe integration of large numbers of UAS operations into the airspace. One of the safety measures consists of the strategic deconfliction of the trajectories, defined as a series of 4D volumes within which the aircraft must remain. A flight authorisation service must prevent these volumes from overlapping (i.e., in time and space) when belonging to different flights. In case of overlap, the flight requests can be rejected or modified to resolve the conflicts and make them feasible. Besides the level of demand, a key factor that contributes to the number of rejected or modified flight requests is how the 4D volumes are defined, including their applicable deviation thresholds. Such definition will impact the airspace capacity and flight approval rate, thereby conditioning access to the airspace. In this work, we identify the advantages and disadvantages of different 4D volume definition decisions. Examples of these decisions illustrate how they affect access to the airspace given different levels of demand. This can help to identify the trade-offs that better fit the specific needs of a given airspace and guide Member States to establish flight authorisation constraints to ensure fair and efficient access to their U-space airspace.

B04. Uncertainty-Aware FLARM-Based Conflict Detection for Low-Altitude UAS Operations

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Safe operation of cooperative unmanned aircraft systems in U-space environments in particular, but also in any other airspace requires surveillance that is accurate, real-time, and reliable to support conflict alerting. FLARM, a low-cost position broadcast technique well-established for gliders may provide electronic conspicuity also for cooperative UAS, though reports can contain communication delay, update-rate limitations, and temporary data gaps. Building on the recent flight-test measurements, where FLARM achieved a 95th-percentile horizontal error of 16.80 m and showed an approximately 1.91 s time offset, the current work investigates an uncertainty-aware FLARM-based conflict detection model for UAS operations with varying flight characteristics, generally having lower inertia than gliders.

The method first characterises surveillance error by aligning FLARM reports received at a ground-based traffic monitoring unit with reference trajectories, estimating sensor-specific time offsets, and modelling residual along-track and cross-track errors as functions of motion state, update time and potential offset, and manoeuvre dynamics from real flight tests. Physics-based baselines, including fixed time-offset compensation, constant-velocity, or constant-acceleration propagation, and Kalman filtering, are compared with lightweight learning-based residual models using Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks.

The corrected trajectory estimate and its uncertainty envelope are then intended to support a probabilistic conflict detection module based on predicted closest point of approach over a 30-second tactical look-ahead horizon. Instead of using fixed geometric thresholds alone, the alert boundary is inflated according to estimated positional uncertainty and track age, enabling more conservative warnings when reports are stale or unreliable. The expected outcome is an FLARM error-aware ground-station alerting framework, with future extension toward onboard receiver-based advisory generation and autopilot-assisted avoidance recommendations.

B05. Spatiotemporal Multi-Modal Sensor Synchronization for High-Speed Aerial Platforms

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Recent advances in visual–inertial navigation and tightly coupled LiDAR–inertial odometry have improved the accuracy and robustness of aerial state estimation. Field deployments have also demonstrated the practical use of synchronized visual, inertial, and LiDAR sensing on unmanned aircraft and full-scale rotorcraft. However, state-estimation performance becomes increasingly sensitive to temporal and spatial alignment as vehicle speed increases. Sensor time-lag, communication delay, and processing latency can introduce significant spatial errors in highly dynamic flight. At typical operating speeds, a millisecond-scale timing errors can produce significant displacement between sensor measurements and estimated state.

This paper presents a framework for spatiotemporal synchronization of an OPAL3 LiDAR with the Inertial Navigation System of the Bell 412 Advanced Systems Research Aircraft. The method addresses nondeterministic delays associated with software timestamping, operating-system scheduling, data transmission, and sensor communication.

The proposed method first transforms raw measurements from an aerospace-grade inertial navigation system to a common GPS-referenced Unix time base. The time-aligned measurements are then interpolated to account for differences in sensor sampling rates and to establish corresponding LiDAR and inertial trajectories. A grid-search optimization is then applied to estimate the temporal offset by minimizing the trajectory root-mean-square error. When temporal alignment is achieved, spatial calibration is performed using linear least-squares estimation to determine the three-dimensional lever-arm between the LiDAR and inertial reference frames.

Experimental flight data are used to validate the proposed framework. The results demonstrate that deterministic timestamping, temporal-offset compensation, and accurate lever-arm estimation improve trajectory estimation accuracy. The proposed approach provides a repeatable synchronization framework for multimodal state estimation on highly dynamic aerial platforms. It establishes a common and traceable time base and improves the reliability of LiDAR–inertial sensor fusion in demanding flight environments.

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Author contributions: Conceptualization, Awantha Jayasiri; Methodology, Ravindu Thalagala; Validation, Ravindu Thalagala and Awantha Jayasiri; Formal analysis, Ravindu Thalagala; Investigation, Ravindu Thalagala and Awantha Jayasiri; Resources, Awantha Jayasiri;

B06. MD-MCTS: Multimodal-Determinized Monte Carlo Tree Search for UAV Multi-Target Rendezvous

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Long-horizon UAV missions such as successive inspection of vessels in a port, or rendezvous with vehicles on a transit network, depend on predictions that are multimodal: the longer the horizon, the more alternative routes remain plausible. We consider a single altitude-hold UAV that must meet several moving targets in sequence, under speed and acceleration limits, so as to maximize the number of contacts within a fixed mission horizon. Multimodal predictions are represented as mixture density networks with weighted Gaussian modes over future target positions. Planning is online and receding horizon and the planner's decision is the next target to visit, not unconstrained continuous control. Greedy interceptors chase the nearest dominant-mode mean and ignore later sequencing, so a high-probability alternate mode can void the intercept and delay the rest of the tour. Standard Monte Carlo tree search (MCTS) can search visit order, but without sampling modes at evaluation time it cannot tell which sequences remain feasible when modes disagree. We present Multimodal Determinized MCTS (MD-MCTS). The tree searches who to visit next. Each simulation samples one mode per target, collapsing the mixture to a unimodal scenario, and scores a greedy completion with a time-discounted capture reward. Averaging over simulations estimates expected visits under the prediction. Domain-specific PUCT priors, using time-to-intercept and dominant-mode confidence, bias expansion toward reachable, high-probability legs. MD-MCTS is evaluated in 2D dynamics with MDN forecasts on synthetic multimodal scenes and on an urban public-transport network reconstructed from OpenStreetMap, where vehicle routes induce multimodal future motion. Relative to a greedy interceptor and non-determinized MCTS, MD-MCTS achieves ~20% more contacts with tight UAV dynamics constraints and a fixed mission horizon.

Author contributions: Conceptualization, Toma Sikora and Vladan Papić; Methodology, Toma Sikora; Software, Toma Sikora; Validation, Toma Sikora; Visualization, Toma Sikora; Supervision, Vladan Papić; Project administration, Vladan Papić;

B07. On the Energy Trade-Offs of Continuous vs. Locked Rotor Tilt Control in Tiltrotor Quadcopters

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Unmanned aerial vehicles are increasingly used in applications where flight time is critical, making energy efficiency a central design concern. Among multirotor platforms, tiltrotor quadcopters stand out by allowing their rotors to rotate about a fixed axis, enabling direct horizontal thrust generation without tilting the entire vehicle, but they introduce a key design question: how should the tilt angle be controlled, and at what energy cost? Two broad approaches exist: fixed-tilt configurations, where the rotor orientation is held constant and maneuvering is achieved through thrust differences, and variable-tilt configurations, where the tilt angle is continuously adjusted during flight. Despite growing interest in tiltrotors, the energy implications of each approach remain largely unexamined. In our previous work, we addressed this gap by developing an online Recursive Least Squares algorithm that identifies the energy-optimal vehicle pitch trim angle in real time, reducing propulsion consumption under wind disturbances while maintaining precise position tracking. The present paper extends these results along three directions: (i) the total energy expenditure of continuous variable-tilt tracking is compared against a fixed-tilt approach, (ii) the parasitic power drain of servo actuators is explicitly accounted for, and (iii) a self-locking worm gear is proposed for the fixed-tilt approach as a practical modification for further energy savings. Bench measurements show that the worm gear draws zero current at idle (versus 0.05–0.09 A for the servo) and reduces the average actuation current by roughly 50%. To achieve precise tracking against wind disturbances, Active Disturbance Rejection Control and Incremental Nonlinear Dynamic Inversion are employed for position and attitude control, respectively. The primary trade-off is actuation bandwidth, with full-range tilt taking approximately three times longer than the servo baseline. These results characterize an overlooked energy–agility trade-off and offer a practical self-locking tilt strategy for endurance-critical missions.

B08. On Real-Time Boresight Estimation for UAV-Based Antenna Measurements: A Hybrid Model Approach

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UAV-based antenna measurements offer a flexible alternative to conventional antenna far-field measurements, but a misalignment with respect to the boresight position can lead to uncentered data files, possibly needing a new round of measurements. Extending our previous work, where we introduced a closed-loop framework combining Moving Horizon Estimation (MHE) with Fisher Information Matrix (FIM)-based Informative Path Planning (IPP) for real-time boresight estimation, this paper extends that framework to non-ideal antenna patterns by introducing a hybrid modelling approach that augments an Airy main-lobe model with low-order spherical harmonic corrections, thus capturing beam deformation and asymmetry. Our estimator, whose IPP part guides the UAV in real-time, starts from the Airy model and activates the additional correction terms online only when the measurements indicate that the circular model is no longer sufficient. The MHE is used to estimate the boresight from sequential UAV measurements integrating physical constraints, while IPP is done using FIM-based greedy D-optimal planning in order for the UAV to select the next waypoint maximizing information gain. This preserves the real-time closed-loop structure of the original method while improving robustness to non-symmetric main lobes. Conventional UAV antenna raster scan typically requires on the order of 2000–5000 sampled points, whereas the proposed closed-loop approach is able boresight estimation within about 40–60 informative measurements depending on pattern complexity. Validation on deformed patterns derived from actual UAV raster measurements show accurate boresight estimation with stable convergence, demonstrating that the method extends efficient adaptive localization beyond the ideal symmetric-beam case.

B09. Ultra-Wideband Localization in Forest Environments: Potential for Drone Applications

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Recently, drones integrated with advanced remote sensing technologies such as GNSS, laser scanning, and cameras have been widely used in forest environments to collect forest data both manually and autonomously. However, as GNSS accuracy is usually poor under forest canopies and GNSS signals are often discontinuous and interrupted by forest canopies, high-performance SLAM algorithms based on laser scanning or camera and IMU data are usually used for navigation and localization of drones in forests. The major challenge of the SLAM-based solutions is that their performance varies considerably across different forest environments. For example, laser scanning-based SLAM algorithms might fail in dense forests due to the obstruction of laser pulses by trees. As a result, SLAM technology highly relies on the algorithm itself as well as the performance of IMU sensor used for reliable trajectory estimation.

Ultra-wideband (UWB) localization, as one of the most popular and accurate close-range positioning technologies for moving platforms, has been widely used in drone applications in indoor environments over the past decade to provide high precision and large-scale positioning solutions. In addition to localization, UWB technology also provides communication capability between devices, making it suitable for drone swarms applications. Moreover, UWB devices are able to form a network precisely and autonomously based only on the ranging measurements between them, making UWB suitable for use in forest environments to overcome the limitations of GNSS. Our preliminary results show that decimeter-level positioning accuracy can be achieved by standalone UWB localization in a forest environment without prior knowledge of the UWB beacons or their positions. All UWB devices can be deployed randomly, and they can be rapidly and precisely discovered and included in the same local network. Therefore, UWB localization has great potential for drone applications in forests.

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B10. Sea-Trial Validation of ANFIS-Based Energy-Efficient Pitch Control for a Buoyancy-Driven Underwater Drone

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Buoyancy-driven underwater drones, commonly referred to as underwater gliders, require accurate and energy-efficient pitch control for long-duration ocean observation. Conventional PID-based pitch controllers may cause repeated movement of the internal shifting mass even after the commanded pitch angle has been reached, resulting in unnecessary actuator operation and cumulative energy consumption over repeated dive cycles.

In previous work, an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based pitch controller was developed to reduce unnecessary internal-mass motion while maintaining pitch-tracking performance. Its performance was evaluated using a nonlinear six-degree-of-freedom dynamic simulator incorporating experimentally derived power-consumption models of the buoyancy engine and pitch actuator. The simulation results showed a **57.05% reduction in pitch-control energy consumption** compared with conventional PID control.

The present study extends this work by validating the proposed controller under **untethered sea-trial conditions** using a 1,000 m-class buoyancy-driven underwater drone. Sea trials were conducted off Pohang, Korea, without a safety tether. The PID and ANFIS-based controllers were compared in terms of the cumulative travel of the internal shifting mass and the horizontal travel distance of the vehicle.

The sea-trial results showed that the ANFIS-based controller reduced the cumulative travel of the internal shifting mass by **58.4%** compared with PID control, while the horizontal travel distance increased by **12.6%** under the tested conditions. These results demonstrate that the proposed learning-based pitch-control strategy can effectively suppress unnecessary actuator motion in a real ocean environment. The sea-trial validation further supports the applicability of ANFIS-based pitch control for improving the operational energy efficiency of buoyancy-driven underwater drones during long-duration ocean missions.

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B11. A First Step Towards Noise-Aware Mission Planning Through Acoustic Geofencing

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The widespread deployment of unmanned aerial systems (UASs) is usually discussed in terms of safety, autonomy, efficiency and airspace integration, while their acoustic impact is still rarely considered during mission planning. However, drone noise can produce immediate effects such as annoyance, sleep disturbance, communication masking and behavioural changes, and may also contribute to long-term impacts on both humans and wildlife, including habitat avoidance, chronic stress and reduced breeding success. For applications such as wildlife monitoring, delivery near protected areas, hospital logistics or flights over noise-sensitive communities, noise should be treated as an operational constraint rather than a post-operation assessment.

This paper presents a first step towards Noise-Aware Mission Planning by introducing an acoustic geoplanning framework based on Acoustic Geofencing. The proposed approach combines three components: (i) an experimentally derived acoustic emission model of the drone, (ii) a simplified sound propagation model to estimate the acoustic footprint along the flight path, and (iii) an acoustic zoning layer defining sensitive targets, threshold values and acoustic fences. Rather than relying solely on conventional geofencing, the framework evaluates candidate routes according to their predicted acoustic impact on nearby receptors, incorporating noise as an additional planning criterion.

The main objective is not to develop a complete autonomous path-planning algorithm, but to demonstrate that integrating acoustics into mission planning requires only a modest modelling effort while providing valuable operational information. Once available, this acoustic layer enables candidate routes to be evaluated before flight, facilitates comparison of alternative trajectories, and provides objective evidence of their acoustic compatibility with predefined thresholds. Beyond reducing disturbance to nearby communities and wildlife, the framework might also help avoid unnecessarily conservative restrictions where the predicted acoustic impact is negligible. The proposed approach therefore provides a practical bridge between drone development and environmental responsibility, supporting safer, more efficient and evidence-based UAS mission planning.

B12. Real-Time Elevation and Orientation-Aware Visual Localization for GNSS-Denied Drone Navigation

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Global Navigation Satellite Systems (GNSS)-denied environments pose significant challenges for autonomous drone navigation, requiring robust visual localization systems capable of real-time performance. Existing approaches either sacrifice accuracy for speed or fail to adapt to varying flight altitudes and orientations, limiting their practical deployment. We present Real-Time Elevation and Orientation-Aware Localization Architecture (REOLA), a visual localization system that combines similarity-driven autonomous window sizing, element-wise correlation-based orientation detection, and reinforcement learning with human feedback (RLHF) enhancement for publicly available satellite imagery. On desktop hardware (i7-10700K + RTX 3070), the REOLA achieved approximately 59 FPS performance with sub-5-m accuracy across diverse flight conditions through intelligent similarity-based matching, combined with efficient MobileNet-V3 embeddings and FAISS similarity search. For embedded deployment on NVIDIA Jetson Orin Nano, the system achieved 22.5 FPS, meeting real-time requirements for autonomous drone localization. The system autonomously selects optimal window sizes corresponding to the current elevation and determines drone orientation through element-wise correlation scoring across discrete rotation angles. Enhanced through RLHF, the REOLA achieved a 97.1% success rate (sub-5-m localization) while processing frames in 17 milliseconds on desktop hardware (44.4 ms on embedded hardware), providing a substantial margin over real-time requirements. The approach demonstrates particular superiority over traditional keypoint-based methods in challenging environments with repetitive patterns such as agricultural fields, rocky mountains, dense forests, and grasslands, where conventional keypoint detection struggles. We explicitly identify featureless sand dune deserts and open-sea or coastal water flights as out of scope, since the reference satellite imagery in those regimes does not contain stable landmarks.

B13. Genetic Algorithm for Terrain-Optimized Routing for UAV and eVTOL Corridor Navigation

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Urban low-altitude operations for unmanned aerial vehicles (UAVs) and emerging electric vertical takeoff and landing (eVTOL) corridor concepts require planners that both guarantee feasibility under hard constraints and optimize metrics linked to energy and safety margins. This work introduces the "GATOR" pipeline, which stands for Genetic Algorithm for Terrain-Optimized Routing. GATOR uses a feasible-first hybrid architecture to solve this routing problem. First, a deterministic 2D grid A* planner finds initial paths that satisfy hard-constraint feasibility like geo-fences and obstacle envelopes. Second, a genetic algorithm (GA) refines these paths over a constrained search space seeded by the feasible A* paths to improve distance, clearance, and climb metrics. Third, a lightweight Monte Carlo tuning loop, designed like a cross-entropy search, stabilizes soft-cost preferences across episodes. To test the pipeline, terrain elevation data is pulled from the USGS Elevation Point Query Service (EPQS), and building footprints are gathered from OpenStreetMap. In experimental run artifacts, the GA refinement successfully improved the best seed objective by approximately 5.5% while strictly preserving path feasibility and maintaining a stable minimum altitude above ground level (AGL) profile. This hybrid approach demonstrates highly repeatable corridor discovery under strong constraints.

B14. From Threat Intelligence to Safe Paths: Cooperative UAV–UGV Navigation in Contested Urban Search and Rescue

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Autonomous Ground Vehicle (UGV) navigation in contested urban search-and-rescue (SAR) settings must balance mission completion against exposure to mobile adversaries whose positions are known only from aging, intermittent observations. This work presents a cooperative UAV-UGV navigation framework in which an aerial agent supplies threat intelligence to a ground agent running a risk-aware A* path planner over a real urban road graph. The core contribution is a temporal decay threat model that attenuates each adversary detection's influence as a continuous function of observation age, combining exponential confidence decay with a worst-case-reachability expanding uncertainty radius, integrated directly into the planner's edge-cost function. Five UAV coverage strategies, no UAV, lawnmower, threat-informed, target-informed, and a novel phase-scheduled hybrid, were evaluated across 300 simulated missions on an OpenStreetMap-derived road network, scored by a composite Mission Performance Index (mission success, adversary containment, time efficiency). At standard adversary density, threat-informed aerial coverage achieves the highest UGV success rate. At triple density, no UAV-assisted strategy outperforms the baseline on the composite index, revealing a critical density threshold - bounded empirically between the two tested densities, beyond which UAV coordination overhead becomes net-negative for ground-agent performance. The results carry direct design implications for density-conditional UAV deployment policies in multi-tier autonomous SAR systems.

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B15. Threat-Aware Trajectory Planning for Full-Scale Helicopters

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Autonomous operation of full-scale rotorcraft in contested environments requires trajectory planning methods capable of responding to threats in real time while maintaining aircraft dynamic feasibility and flight-envelope constraints. This paper presents a threat-aware trajectory planning framework for full-scale helicopters that integrates real-time threat information with a motion primitives-based trajectory generation architecture. The framework converts an abstract waypoint mission into a smooth, dynamically feasible 3D reference trajectory while accounting for operational constraints, including airspeed, acceleration, bank angle, climb/descent, and turning limitations. Threat information is received in real time as Cursor-on-Target messages through the Team Awareness Kit network and processed to determine the threat location and corresponding avoidance region. Upon detection of a threat affecting the nominal trajectory, the planner searches a precomputed library of polynomial motion primitives representing dynamically feasible helicopter maneuvers. Appropriate polynomial coefficients are selected based on the aircraft state, threat geometry, and operational constraints and integrated to construct a smooth avoidance maneuver. The resulting avoidance segment is seamlessly stitched into the nominal three-dimensional reference trajectory, enabling rapid replanning without solving a computationally expensive trajectory optimization problem from scratch. The modified trajectory is subsequently tracked using a nonlinear model predictive control framework operating in real time. The complete architecture is implemented within a modular Robot Operating System environment and evaluated using the National Research Council Canada Bell 412 Advanced Systems Research Aircraft platform. The proposed approach was first validated using the NRC Bell 412 digital-twin simulation environment and subsequently implemented and evaluated through full-scale helicopter flight experiments involving multiple threat messages transmitted through the TAK network. Results demonstrate successful real-time generation and execution of smooth threat-avoidance trajectories while preserving vehicle feasibility and mission continuity. The proposed framework provides a computationally efficient and practically deployable approach for incorporating dynamically evolving tactical information into autonomous trajectory planning for full-scale rotorcraft.

Author contributions: Conceptualization, Awantha Jayasiri; Methodology, Awantha Jayasiri; Software, Awantha Jayasiri;

B16. Active Antenna-Aware UAV Navigation for Real-Time RF Mapping and Source Localization

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Search-and-rescue (SAR) operations increasingly employ UAVs in environments where optical and thermal sensing may be degraded by vegetation, debris, smoke, or structural obstruction. Radio-frequency (RF) localization provides a complementary approach when a victim or target carries a cooperative wireless device. This work presents an ongoing implementation of an active UAV-based RF localization framework in which the UAV is treated as an adaptive sensing platform rather than as a passive carrier following a predefined trajectory.

The proposed approach follows a measure–estimate–move strategy. RF ranging measurements are combined with UAV pose information to iteratively estimate the position of a ground-based transmitter and the associated localization uncertainty. The next UAV pose is then selected according to the expected reduction in localization uncertainty while accounting for motion cost and predicted measurement reliability. Candidate actions include waypoint displacement, altitude adaptation, yaw rotation, and local probing trajectories. In particular, the framework considers that UAV orientation and antenna geometry may affect ranging bias, measurement availability, and sensitivity to multipath and non-line-of-sight propagation.

The experimental implementation is currently in progress using low-cost ESP32-S3 as RF nodes and UWB devices for validation. The first validation stage will characterize ranging error, variability, measurement availability, and signal-quality indicators under controlled changes in distance, altitude, relative orientation, antenna mounting, and propagation conditions. Ground-truth UAV position and attitude will be used to derive empirical measurement-quality models that can subsequently inform next-best-pose selection.
The active localization strategy will then be compared with passive or predefined UAV trajectories under common operational budgets. Performance will be evaluated in terms of ranging and localization error, convergence, measurement reliability, traveled distance, and motion or energy cost. The objective is to determine when adapting UAV sensing geometry and orientation can provide more reliable and efficient RF-source localization than collecting measurements along fixed flight paths in SAR scenarios.

B17. Towards a Shared Understanding for UxV Swarming

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Since 2020, UxVs have revolutionized warfare, primarily because of the conflict in Ukraine where uncrewed platforms are routinely deployed by the tens of thousands on a daily basis. With the industrial ecosystem slowly rising to the challenge of mass-producing these platforms, it is only a matter of time before such devices are being deployed in large cooperating groups. By 2030, we will have autonomous swarms operating on the battlefield and, depending on how you define the term "swarming", this is already the case. The lack of a shared understanding of what that term "swarming" means is increasingly becoming an issue. The reason for this is that the term swarming has become a hype word, used almost indiscriminately for a broad range of concepts and ideas by various involved parties. This makes a shared understanding almost impossible and therefore impacts the conversation between stake holders, researchers and industry. With the goal of designing and building operational high-TRL (Technology Readiness Level) swarms that can be deployed for mission-specific purposes in contested adversarial environments, we need a means to facilitate an understanding between those meant to operate such swarms (who have needs and requirements), those responsible for deploying swarms (who are subject to operational constraints and legal frameworks) and the engineers and researchers who will create the systems that can form a swarm. We believe that this is best done not through a lengthy definition of the term itself, but by instead (1) considering various relevant aspects (such as human control, inter-swarm communication, and localization) and (2) mapping prominent use-cases to them. The resulting clusters will be meaningful fragments of the full space the term swarming inhabits. This paper / talk will propose a methodology to achieve such an understanding.

B18. Reframing Military UAS Challenges Through Systems Engineering and Operational Reality

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For more than two decades, defense roadmaps have envisioned a progression from remotely piloted unmanned aircraft systems (UAS) toward increasingly autonomous platforms, collaborative operations, and ultimately large-scale autonomous swarms. Although advances in autonomy and artificial intelligence have been significant, evidence from recent conflicts suggests that many of the most pressing challenges affecting military UAS stem not from insufficient autonomy, but from vulnerabilities in communications, navigation, endurance, logistics, survivability, and integration. This paper presents a systems-engineering assessment of the factors governing UAS performance in contested environments, drawing on operational lessons and published studies. The analysis examines communications robustness, operation in GNSS-denied environments, onboard computing constraints, endurance, sustainment, survivability, and the interactions among these elements across the broader UAS architecture. The findings indicate that assured communications, navigation, endurance, survivability, and sustainment form the foundation upon which advanced autonomous functions depend. The paper also evaluates the role of Digital Mission Engineering and Model-Based Systems Engineering in assessing future force concepts while highlighting their limitations in anticipating disruptive innovation. Its principal contribution is a framework that challenges prevailing investment priorities and argues that the future military value of UAS will depend less on higher levels of autonomy than on robust, adaptable, and sustainable architectures operating effectively in highly contested environments.

B19. Flight Altitude and Data Quality in Drone-Based Hyperspectral Imaging for Grade Control in Open-Pit Mining

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Grade control decisions in open-pit mining determine the destination of mined material (e.g. processing, waste). Blast movement modelling translates in situ resource models into muckpile projections that define material units at the point of excavation. However, these projections are rarely checked against independent datasets after blasting. Drone hyperspectral imaging (HSI) can provide such a check by mapping mineralogy directly on the muckpile surface. Yet signal quality is seldom assessed in mining HSI applications, where signal-to-noise ratio (SNR) is generally taken as the nominal sensor value, disregarding both its variation across the spectrum and the effect of acquisition choices on the signal. This study examines whether flight altitude affects the SNR of drone-HSI over a muckpile, evaluated at the absorption features diagnostic of the target mineralogy, to establish whether lower-altitude missions with higher spatial resolutions are justified. HSI data were acquired over a single muckpile at three altitudes (40, 80 and 120 m) under identical sensor settings, with mosaic pixel sizes of 3, 5 and 6 cm respectively. The drone-HSI system comprises a NOA hexacopter (Acecore Technologies) carrying a HySpex Mjolnir VS-620 sensor (Norsk Elektro Optikk). Data were georectified and converted to at-surface reflectance, masked for shadows and oversaturated pixels, and restricted to the ground common to all three datasets. Per-band SNR was then estimated from the image data using identical processing parameters. SNR was highest at 80 m in all diagnostic windows and lowest at 40 m. The 40 m mission required 2.9–3.5 times the imaging time and data volume of the others. Under the illumination of each flight, lower altitude did not improve signal quality, suggesting that missions should be justified radiometrically, not by pixel size. These results provide the data-quality baseline for comparing HSI products against muckpile projections in the next stage of this research.

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B20. From Source to Sea: UAV-Based Monitoring of Plastic Litter in Water and Coastal Environments

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Plastic items are transported across interconnected freshwater, transitional, and marine environments. Tracking it across this continuum is essential for understanding its distribution and for designing effective mitigation strategies. The ADRIPLAST project addresses this need by developing a joint monitoring framework for plastic and microplastic pollution that combines in-situ observations, laboratory analyses, and indirect monitoring approaches across aquatic systems. This study assesses unmanned aerial vehicles (UAVs) as a supplementary method for locating and mapping visible meso- and macroplastic debris in river, transitional, and coastal zones. High-resolution UAV images allow for identifying litter items, estimating their spatial density, and analyzing their distribution concerning land cover, vegetation, river shape, and coastal features. Multiple surveys also track temporal shifts in litter accumulation and redistribution, providing a dynamic perspective that a one-time sampling cannot provide. Beyond litter detection itself, UAV-derived products can guide field monitoring by flagging accumulation hotspots and priority sectors for ground surveys, sampling, and clean-up operations. Integrating UAV data with in-situ observations improves spatial coverage, increases survey repeatability, and enables direct comparison across environments along the source-to-sea continuum — capabilities that are difficult to achieve through ground-based sampling alone. This approach supports the broader ADRIPLAST strategy, combining direct sampling and remote sensing to monitor meso- and macroplastics in freshwater, transitional, and coastal pilot zones. By integrating UAV-derived spatial data with field observations, it helps develop a more comprehensive and operational monitoring system—facilitating evidence-based management and pollution mitigation in the Adriatic–Ionian region.

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B21. UAV-Based Synthetic Aperture Radar: State of the Art and the Road Ahead

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In recent years, Unmanned Aerial Vehicle (UAV)-based Synthetic Aperture Radar (SAR) has seen an unprecedented growth in both the scientific and industrial communities. The low initial and operational costs, the high flexibility of the platform, the increased reliability and accuracy of navigation units, and the simplified regulatory procedures for flight operations are just a few of the key factors that make UAVs an attractive platform for remotely sensing natural or anthropogenic scenarios using SAR.

The technology behind SAR is rather simple: while the UAV is flying, the radar payload transmits pulses and records the echoes. By jointly processing these echoes, a high-resolution image of the scene can be formed. The images are weather-independent, and they can be formed day and night.

The peculiarity of UAVs is that they allow for complete freedom (within the laws of the country where the UAV is flying) about the design of the trajectory including the height, the shape (circular, linear, elliptical, spiral-like, and so on), the velocity and, most importantly, the repetition frequency to observe the scene multiple times with a temporal baseline that can range from seconds to hours or days. This freedom of operation opens the possibility for a large number of applications, such as change detection using amplitude images, deformation monitoring using SAR Interferometry, under-foliage imaging, snowpack analysis using SAR Tomography, agricultural monitoring, search and rescue in hostile environments, and many more. The contribution also discusses emerging technological trends and future application scenarios, including multistatic and distributed SAR imaging, cooperative UAV swarms, autonomous sensing systems, and other next-generation remote sensing paradigms.

B22. Mar_Spectra: A UAV-Based Spectroradiometric Platform for Above-Water Environmental Monitoring

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Miniaturized optical sensors now allow unmanned aerial vehicles (UAVs) to perform high-resolution monitoring over water surfaces. We present Mar_Spectra, a lightweight UAV-mounted spectroradiometric platform for above-water measurement of ultraviolet and visible reflectance at centimetric spatial resolution. The system was designed as a general airborne sensing platform rather than for one specific target: it combines compact instrumentation, real-time acquisition, and optimized flight protocols for rapid coastal surveys. The payload integrates a miniature UV-VIS spectrometer, an embedded Raspberry Pi controller, GPS, an altimeter, wireless communication, and synchronized RGB imaging, and is suitable for multirotor operation. We developed a full acquisition workflow that covers radiometric calibration, quality control, automated metadata recording, and the tuning of flight altitude, sensor-to-water distance, and acquisition settings to keep measurements stable while limiting rotor-induced surface disturbance. As a proof of concept, we tested the platform for detecting sunscreen-derived ultraviolet filters in coastal waters. Controlled laboratory experiments gave a strong linear relationship between a UV spectral index and UV-filter concentrations measured chemically (R^2 = 0.964), and successive field campaigns showed that the system resolves spatial gradients of surface contamination under real operating conditions. Wind, suspended sediments, and phytoplankton were the main factors limiting detection. Beyond this case, the modular architecture can take additional optical sensors and address other environmental targets, offering a low-cost approach to UAV-based monitoring of coastal and inland waters.

B23. Unmanned Aerial Vehicles in Antarctic Research: A Multi-Sensor Review

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Antarctica is one of the most challenging environments for scientific fieldwork, where extreme weather, logistical constraints, and fragile ecosystems limit traditional survey methods. Over the last decade, unmanned aerial vehicles (UAVs) have become valuable tools for overcoming many of these challenges. This review synthesizes results from successive Antarctic campaigns in the South Shetland Islands, primarily on Deception and Livingston Islands, to evaluate the contribution of UAV-based remote sensing to polar ecosystem monitoring. Applications include centimeter-scale topographic mapping of volcanic coastlines, thermal surveys of fumarole fields, automated penguin population assessments using deep-learning models, characterization of guano-driven vegetation gradients through spectral analysis, and detection of red snow algal blooms. These studies employed a range of sensors, including RGB, multispectral, hyperspectral, thermal, and LiDAR systems, often integrated with Sentinel-2 imagery to link local observations with regional-scale patterns. We also describe a UAV-operated water-sampling system for trace-metal and nutrient analyses, extending drone applications beyond imaging to direct environmental monitoring. Across all case studies, UAVs provided rapid, accurate, and low-impact data acquisition while reducing disturbance to sensitive habitats and wildlife. Many of the resulting datasets have been made openly available, supporting wider scientific use. Collectively, these experiences demonstrate that UAVs have evolved from experimental platforms into established tools for polar research, significantly enhancing observational capabilities and improving our understanding of Antarctic ecosystem responses to climate change.

B24. Autonomous Multi-Temporal UAV Monitoring of the Belvedere Glacier Using DJI Dock 2 for Hydrogeological Hazard Assessment

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Glaciers in the European Alps are undergoing rapid retreat and thinning as a consequence of climate change, increasing the frequency and magnitude of hydrogeological hazards that threaten mountain ecosystems, local communities, tourism, and infrastructure. Although Unmanned Aerial Vehicle (UAV) photogrammetry provides a cost-effective solution for high-resolution glacier monitoring, repeated multi-temporal surveys in high-alpine environments remain challenging due to logistical constraints, limited accessibility, and the operational risks faced by field personnel. This study presents an innovative autonomous monitoring approach developed within the MOHYCAM project, based on the deployment of the DJI Dock 2 equipped with the DJI Matrice 3TD, a UAV integrating RGB and radiometric thermal sensors for continuous monitoring of the Belvedere Glacier (Monte Rosa Massif, Italy) and its surrounding unstable slopes above the village of Macugnaga. The study area is particularly prone to debris flows and other glacier-related hazards, as demonstrated by recent events that have affected both the glacier forefield and nearby inhabited areas. The project aims to establish a multi-sensor early warning system capable of acquiring high spatial and temporal resolution datasets over extensive and difficult-to-access mountain terrain. The autonomous operation of the DJI Dock 2 enables scheduled flights with minimal human intervention, significantly reducing operational costs while improving safety by limiting field exposure of pilots and operators. Beyond hazard monitoring, the system supports applied research on permafrost degradation processes, which play a fundamental role in the stability of glacier moraines. The radiometric thermal imagery acquired by the DJI Matrice 3TD enables repeated surveys throughout the day, allowing the investigation of diurnal thermal dynamics and their relationship with permafrost evolution and slope instability. This autonomous UAV-based framework represents a scalable and efficient solution for long-term monitoring of glacierized environments under changing climatic conditions.

B25. UAV-Based Forward Modeling of Bare-Soil Reflectance in Saline Drylands: Integrating DART-Lux and the Hapke Model

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High-resolution UAV observations provide an important means of characterizing soil salinization patterns in dryland environments, where salt accumulation varies substantially over short distances. However, UAV based multispectral reflectance models often exhibit limited transferability across sites and acquisition dates because soil reflectance is influenced by confounding factors including illumination geometry (BRDF), surface roughness, and soil moisture. These effects cannot be reliably separated from the intrinsic soil spectral response without explicit physical modeling. This study develops and validates a physics based forward simulation as a key step toward correcting these effects. We focus on a salt affected bare soil site within the Sehb El Masjoune saline dryland topographic depression, Rhamna region, Morocco, surveyed using a MicaSense RedEdge P multispectral sensor (475–842 nm). A three dimensional mesh of approximately 1.48 million triangles generated from a photogrammetric DSM was segmented into 20 reflectance classes via K means clustering. For each class and band, Hapke single scattering albedos were retrieved through inversion of the Hapke model. A previously undocumented wavelength dependent internal scaling factor in DART's Hapke database was identified, empirically quantified, and corrected. The grouped scene was simulated using DART Lux and evaluated against the calibrated orthomosaic at scene, distribution, and terrain scales. Results show close agreement: scene mean reflectance deviates by less than 2.5% per band; histogram correlations exceed 0.94; and at 2 m terrain scale, simulated versus measured cell means reach correlation around 0.95 with relative RMSE near 2%. The validated forward model provides a physically controlled environment for generating synthetic observations under modified surface conditions, enabling isolation of roughness effects induced by rainfall runoff, soil cracking, and erosion. Soil moisture effect elimination is currently being incorporated, with extension to a second site and soil salinity retrieval planned as subsequent steps.

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B26. Mission Templates and Event-Driven Handover for Persistent Multi-Drone Inspection and Mapping

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Persistent drone operations require more than isolated autonomous flights. Inspection, mapping, and emergency-response missions must remain active as batteries deplete, vehicles become unavailable, tasks are interrupted, and priorities change. This work extends Swarm-Steward, a natural-language multi-robot coordination system using an LLM-driven multi-agent architecture, toward persistent autonomy with limited human intervention. Operators specify goals, while the system grounds requests in geospatial context, telemetry, and aerial perception, then executes them through deterministic tools and priority-based task queues.

The main contribution combines reusable mission templates, event monitoring, and queue-aware handover. Mission templates define workflows for industrial asset inspection, aerial mapping, stockpile monitoring, hotspot assessment, search and rescue, and follow-up inspection of detected events. These workflows combine take-off, lawn-mower coverage, nadir and oblique camera angles, 3D feature orbits, adaptive gimbal control, and safety-validated trajectories. Mission targets can be known map objects, manually defined locations or areas, or dynamic features produced from drone video streams through detection, geolocation, and cross-drone fusion. This allows the same instruction to address planned, operator-defined, and unexpected targets.

Event-driven handover enables Swarm-Steward to monitor progress, telemetry, queued actions, and priorities, and to react when a drone reaches a battery threshold, becomes unavailable, is interrupted, or a higher-priority event appears. Unfinished actions and pending queues can be inherited by another drone or replacement group while preserving target references, task order, priorities, and execution history. The system has been tested with real drones and integrated with an Unreal Engine-based simulator for digital-twin-style visualization, mission preview, and operator feedback. It is being developed for biomass power-plant scenarios, where imagery of large fuel stockpiles supports mapping, volume estimation, and hotspot inspection. Humans remain responsible for goals, confirmation, feedback, and supervision, while mission templates and event-driven handover allow missions to continue beyond individual drone endurance.

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