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Geospatial Intelligence for UAS

Enhancing Mission Success in Dynamic Military Environments

Contents

Introduction

Uncrewed Aerial Systems (UAS) have become a cornerstone of modern and future military operations. Their versatility and effectiveness make them indispensable in many critical missions, including military logistics, intelligence, surveillance, reconnaissance (ISR), and target acquisition. However, as these platforms increasingly carry valuable payloads and perform sensitive tasks, they also become high-priority targets in contested environments.

The operational environment in military operations is often fluid and unpredictable. Terrain features, infrastructure, and threat landscapes can change rapidly, rendering previously accurate geospatial data obsolete. Uncrewed Aerial Vehicles (UAVs) tasked with critical missions must be able to navigate these dynamic conditions and avoid emerging threats.

This evolving threat landscape underscores the importance of precise, adaptive, intelligence-driven mission planning. Geospatial analysis empowers UAVs to adapt to these challenges by enhancing situational awareness and supporting human and autonomous decision-making processes. These geospatial capabilities significantly improve the reliability and predictability of UAV missions, ultimately increasing the likelihood of mission success in complex and contested environments.

Geospatial Analysis

Geospatial analysis significantly enhances the capabilities of UAS in military operations by providing accurate, timely and actionable intelligence for mission planning and execution. UAS operating across diverse and often hostile environments benefit from improved situational awareness enabled by geospatial data, supporting both human operators and autonomous systems.

Geospatial analysis supports critical decisions throughout the mission lifecycle, from platform selection and route optimisation to identifying safe take-off, supply and landing zones. The use of geospatial capabilities helps mitigate risks associated with frontline operations, increasing mission reliability and predictability, and contributing to cost efficiency and resource preservation.

The geospatial analysis capabilities outlined in this paper can be combined to support a variety of mission-critical functions. These include:

/ Terrain and Environmental Mapping
/ Threat Detection and Predictive Analysis
/ Route Optimization and Re-Routing
/ Target Recognition and Verification
/ Autonomous Decision Support
/ Mission Simulation and Planning
/ Post-Mission Analysis and Intelligence Feedback

Together, they form a comprehensive framework that improves the effectiveness, adaptability and resilience of UAS operations in complex and rapidly evolving military environments.

The role of up-to-date, high-resolution geodata

Geospatial data is the foundation for situational awareness, mobility and decision-making in military operations. The accuracy of this data directly influences mission planning, route efficiency, environmental assessment and the safety of personnel and equipment. In rapidly changing operational environments, using outdated maps and terrain data can result in miscalculations, compromised missions and the loss of critical assets.

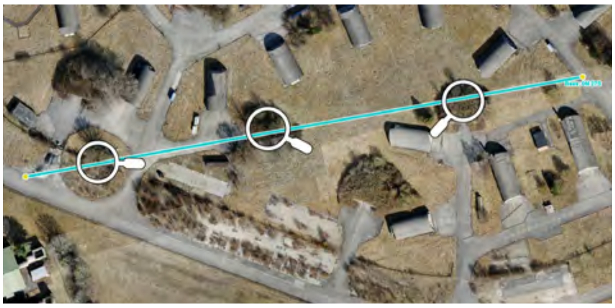
Traditional sources, such as satellite imagery, often fall short in terms of update frequency, viewing angles and spatial resolution. As a result, armed forces are increasingly turning to AI-powered tools and UAV-based data collection to bridge this gap.

Leveraging AI-assisted computer vision transforms real-time UAV data into high-resolution, semantic 3D maps. This advanced capability enables detailed terrain classification and continuous geodata updates, effectively dynamizing geospatial analysis. The outcome is a new generation of near-live navigability maps and terrain assessments that integrate seamlessly into mission planning systems.

The image above shows AI-generated land cover data from a UAV video. The red areas are obstacles, the green and orange areas are grass and fields, and the grey areas are paved areas such as roads.

This capability enables real-time mission planning and rapid adaptation to environmental or tactical changes. It is powered by geodata that is updated every minute. The result is an intuitive, precise and highly adaptive planning foundation, which is particularly critical for autonomous operations where responsiveness and accuracy are essential for mission success.

The image below shows a route for a UAV, using only low-resolution terrain data. When overlayed on a frame from a recent drone video, it becomes clear that the planned route crosses several trees.



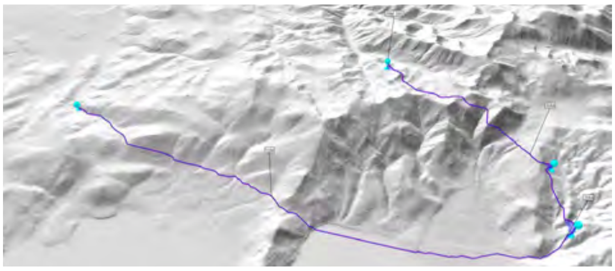
When the real-time generated up-to-date, high-resolution data is incorporated into the UAV's routing scenario, the route no longer traverses obstacles such as trees, and the route is safe and fast.

This seamless fusion of AI and geospatial technology not only improves data accuracy, but also opens up new possibilities for AI-driven decision-making – optimizing navigation, improving situational awareness and revolutionizing operational strategies.

Tactical UAV Routing

UAV routing is a fundamental element of the mission planning process. It requires the calculation of safe and efficient nap-of-earth flight paths, taking into account the UAV's flight characteristics, the terrain, threat exposure and other analytical inputs. These routes are designed not only to guide the UAV to its destination, but also to facilitate the real-time generation of return legs, alternative paths and emergency escape routes.

Advanced routing algorithms provide precise journey time estimates, which are essential for synchronising UAV movements with ground operations. Incorrect timing, such as a UAV arriving minutes ahead of troops who require hours to reach a rendezvous point, can compromise mission success and safety. Accurate routing ensures that assets depart and arrive at the right time and operate with maximum efficiency and minimal risk.

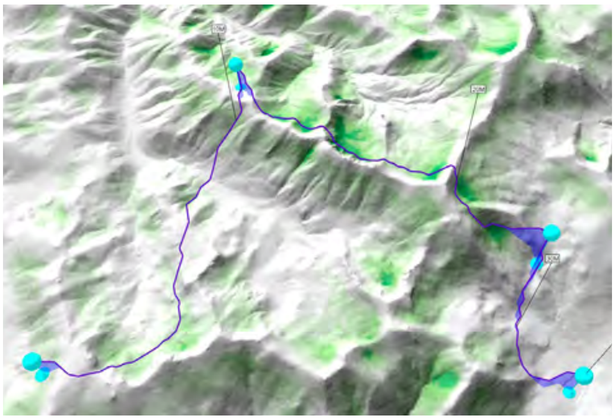


Stealth and Concealment

Analysing 3D coverage is essential for identifying terrain features that offer natural stealth and concealment, which makes it a critical asset when planning safe and covert UAV routes. This analysis also provides valuable insight into the concealment potential of drop zones and landing areas, helping planners to select locations that minimise the risk of detection by hostile forces.

Terrain features such as ridges, valleys and changes in elevation play a pivotal role in enabling UAVs to move undetected. Effective route planning requires these features to be leveraged or avoided depending on the operational context. For instance, flying along the reverse slope of a ridge can shield a UAV from enemy observation, while valleys may provide low-altitude corridors for nap-of-the-earth flight.

Integrating 3D terrain analysis into geospatial workflows enables mission planners to design routes and drop zones that maximise cover and minimise exposure while aligning with tactical objectives, thereby enhancing both survivability and mission success.



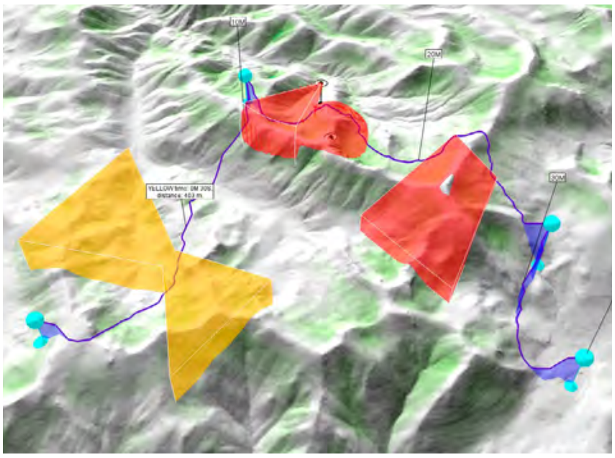
Line-of-Sight Analysis

Line-of-sight (LOS) analysis is crucial for identifying areas where UAV operations, such as resupply drops or pick-ups, may be vulnerable to enemy observation or interference. By evaluating visibility from various vantage points, LOS analysis helps to determine where drones can operate safely and undetected while maintaining communication links and GNSS signal integrity for navigation.

This capability also supports the safety of ground forces by revealing potential threats in and around drop zones. LOS analysis is applicable across multiple use cases, including:

- Determining what is visible from specific locations to guide asset or sensor placement.
- Assessing enemy visibility to ensure that selected locations and flight paths remain concealed.
- Validating that routes and rendezvous points are shielded from hostile observation.

When combined with other geospatial tools and operational data, such as sensor coverage, restricted zones and terrain analysis, LOS analysis ensures that UAV flight routes comply with all mission constraints. This integrated approach enhances the accuracy, safety and effectiveness of UAV operations in contested environments.

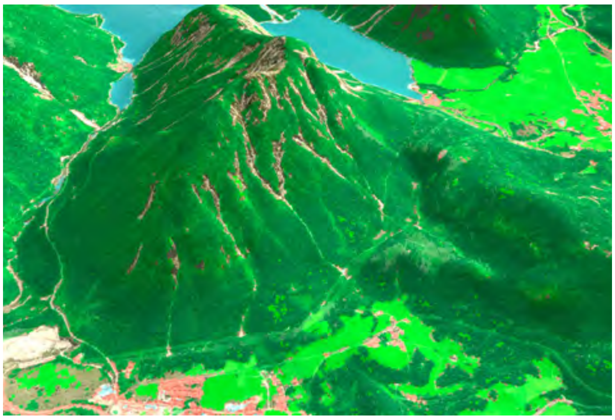


Site Selection for UAV Landing, Supply, and Pick-Up

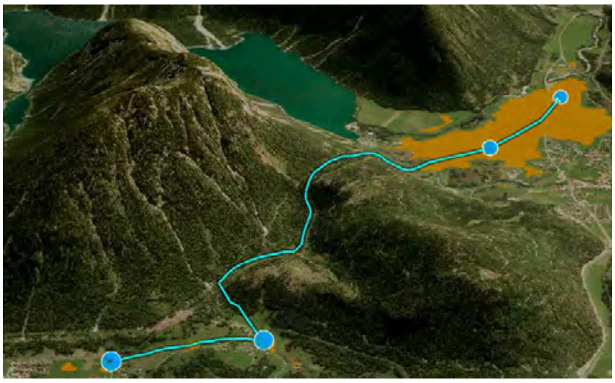
Numerous operational scenarios exist where identifying a safe and accessible landing zone is critical, such as frontline resupply, emergency medical deliveries, and last-mile logistics. These zones must meet a variety of tactical, environmental and logistical criteria to ensure the success of the mission and the safety of the platform.

This process is driven by a comprehensive geospatial analysis that integrates various data layers, such as terrain, land use, infrastructure, buildings, roads and 3D models, as well as UAV-specific flight characteristics. The aim is to identify locations that are physically suitable for landing, tactically advantageous, and logistically accessible.

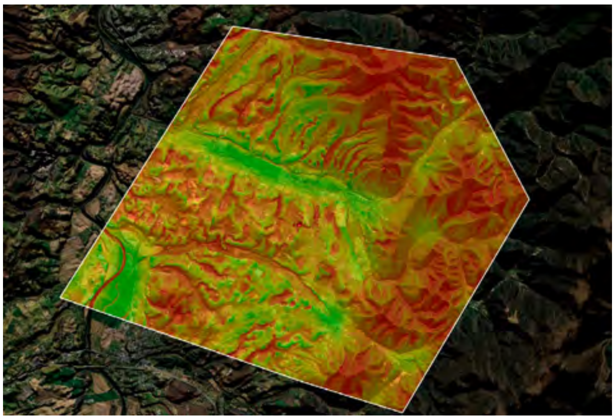
The first step is to analyse terrain data to determine potentially suitable landing areas. In a simplified classification scheme, dense forests are represented by dark green, urban areas by red, bodies of water by blue, and open grasslands by light green. In this example, open grasslands are considered suitable for UAV landings. In real-world applications, however, a much broader and more detailed classification system is employed to reflect the operational environment's complexity.



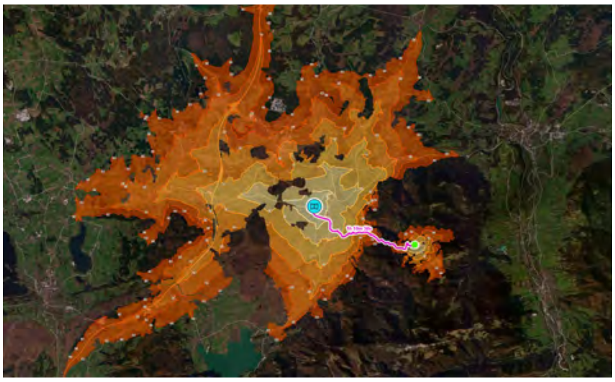
To enhance safety, buffer zones are applied around hazardous terrain types to ensure that UAVs maintain a safe distance from obstacles and high-risk areas. At the same time, elevation data is analysed to exclude areas with steep slopes, since UAVs require relatively flat ground for safe landing. This is achieved by processing digital terrain models (DTMs) to calculate slope gradients and identify sufficiently large, level areas.



Another critical component is visibility analysis, which assesses how exposed a potential landing zone is to enemy observation. This is usually shown using a visibility index, which is represented by a colour scale ranging from green (high visibility) to red (low visibility). Areas with low visibility from known enemy positions are favoured as they provide natural concealment and reduce the risk of detection during delivery or collection.



In many operational scenarios, the most effective delivery or collection point is not located directly on the front line. It may therefore be more practical and secure to identify a nearby rendezvous point that is both reachable and tactically advantageous.

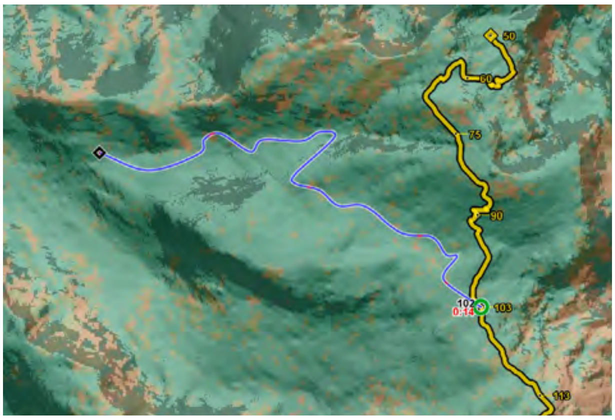


To support this, isochrone analysis is used to visualise travel times from the ground unit's current location. This enables planners to swiftly determine which potential rendezvous points are accessible within a given timeframe. Overlaying these isochrones onto the operational map enables decision-makers to select the most efficient and secure meeting location.

Dynamic Intercept and Supply Point Calculation

Modern weapon systems are defined by their high mobility and speed, which introduces significant complexity in planning timely and secure supply or intercept points. Delays or mismatches in arrival times can expose both UAVs and ground assets to unnecessary risk. To minimise these vulnerabilities, UAVs should ideally arrive at the designated point at the same time as the weapon system to avoid leaving them in exposed areas for any longer than necessary.

Real-time geospatial analysis combined with live positional data enables the dynamic calculation of optimal supply and intercept points. These calculations adapt continuously to environmental changes and tactical updates, ensuring new rendezvous points are generated in real time. This adaptability is crucial for maintaining a flexible and resilient supply chain and for executing precise interception missions in rapidly evolving battlefield conditions.



In the illustrated scenario:

- The yellow line represents the route of the weapon system.
- Yellow time markers indicate the estimated time (in minutes) for the weapon system to reach each potential supply or intercept point.
- Black time markers show the UAV's estimated arrival time at those same points.
- Red segments highlight the UAV's exposure time in open terrain.

In this example, the UAV reaches the intercept point at the same time as the weapon system and is exposed in open terrain for only 43 seconds — a minimal risk window. This level of precision enables rapid and informed decision-making, significantly enhancing the efficiency and safety of supply operations, particularly in unpredictable and high-threat environments.

Beyond Visual Line-of-Sight: Advanced Propagation Models

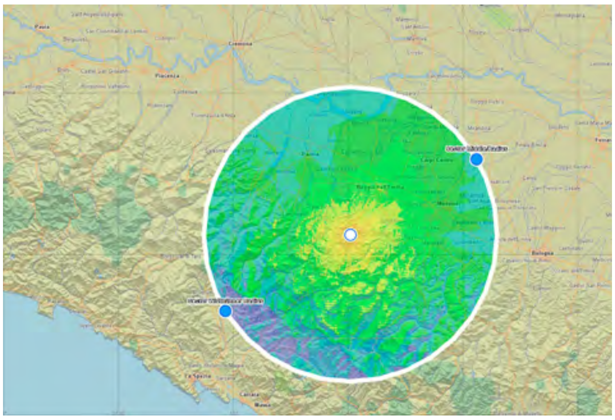
While traditional visual line-of-sight (LOS) analysis is a powerful tool for assessing visibility and exposure, it is not always sufficient for complex operational environments. Often, alternative propagation models are needed to account for various types of signal behaviour and environmental interactions. These models enhance the capabilities of geospatial analysis, enabling more accurate predictions and safer UAV operations.

The same LOS, visibility and coverage analysis techniques can be adapted to work with various advanced propagation models, including:

- Radio frequency (RF) propagation, which helps assess communication coverage and signal strength in varied terrain.
- Sound propagation models, useful for analysing acoustic signatures above or below ground or water.
- Trajectory propagation models, which simulate the path of moving objects such as projectiles or UAVs under specific environmental and physical conditions.

These models improve situational awareness and predictability on the battlefield, helping to generate safer and more effective routes for UAVs. For instance, advanced propagation analysis can be employed to:

- / Evaluate GPS coverage along UAV flight paths to ensure uninterrupted navigation.
- / Assess radio communication coverage, including traditional systems and more complex networks like Mobile Ad-hoc Networks (MANETs).
- / Perform radar detection and gap analysis, optimizing friendly radar coverage while avoiding detection by enemy systems.
- / Analyse enemy weapon system coverage, including direct and indirect fire zones, to reduce exposure to hostile attacks.
- / Conduct blast impact assessments, predicting the effects of potential strikes from either side.
- / Model sound propagation to ensure that vehicles or UAVs remain acoustically concealed from enemy forces or sensors.



Integrating these models into geospatial workflows enables mission planners to make data-driven decisions that account for a broader range of operational variables, ultimately improving the safety, stealth and success of UAV missions in contested environments.

Summary

Geospatial analysis plays a transformative role in enhancing the capabilities of UAVs for military missions. By providing accurate, timely and actionable intelligence, it enables informed decision-making, precise planning and effective execution in a variety of operational environments, many of which are complex, contested and rapidly evolving.

As military operations become more dynamic and data-driven, the importance of geospatial analysis in ensuring mission success and maintaining situational awareness increases. This paper explores how advanced geospatial capabilities, ranging from terrain analysis and visibility modelling to real-time routing and landing zone identification, can significantly improve the performance, safety and adaptability of UAS missions.

Leveraging cutting-edge technologies and customisable tools, such as those offered by Carmenta, enables military forces to integrate real-time geospatial intelligence into their operational workflows. These tools help to answer mission-critical questions, enabling both human operators and autonomous systems to make fast and informed decisions in high-pressure situations.

Carmenta’s geospatial analysis tools provide the capabilities that can help military personnel or autonomous systems make these informed decisions, not only for the scenario explored in this paper, but also for many others.