A Survey of UAV-Based Target Search and Object Detection in Autonomous Exploration and Aerial Surveillance

Abstract

This survey paper examines the integration of Unmanned Aerial Vehicles (UAVs) with advanced computer vision technologies and their transformative impact across various sectors. By enhancing capabilities such as target search, autonomous exploration, and object detection, UAVs have become pivotal in applications ranging from agriculture to counterterrorism. The study highlights the critical role of artificial intelligence (AI) and interdisciplinary collaboration in addressing regulatory and ethical challenges. Recent advancements in deep learning and computer vision have enabled the development of autonomous UAV systems capable of performing complex tasks, including non-destructive inspections and real-time human action recognition. These technologies have facilitated safe navigation and effective 3D reconstruction in dynamic environments, as demonstrated in tunnel inspection scenarios. The integration of AI into UAV networks has furthered innovative applications in disaster management and surveillance, significantly enhancing operational efficiency. The survey also explores the potential of UAV forensics in aiding investigations related to UAV incidents, emphasizing the need for continued research and development in this rapidly evolving field. Future research directions include optimizing energy efficiency, improving swarm autonomy, and enhancing security measures, which are expected to drive further innovations and expand the applicability of UAVs across diverse operational contexts.

1 Introduction

1.1 Significance of UAVs in Modern Applications

Unmanned Aerial Vehicles (UAVs) have become transformative tools across various sectors, significantly enhancing operational efficiency and fostering innovation. In agriculture, UAVs play a crucial role in precision agriculture by enabling non-invasive in-field analyses and plant phenotyping, which improves the accuracy of evaluating plant traits [1]. Their capacity for autonomous monitoring of agricultural environments is pivotal for modern farming practices.

In safety and surveillance, UAVs enhance operational safety and facilitate autonomous operations, addressing significant concerns such as mid-air collision risks through advanced vision-only safety systems [2]. They are also vital in search and rescue missions, employing audio-based localization systems that surpass traditional video-based solutions [3].

UAVs are increasingly utilized for infrastructure monitoring and environmental conservation, showcasing their ability to autonomously detect hazardous radiation sources, which is crucial in high-risk environments [4]. Additionally, they enhance flight safety during low-altitude operations by detecting power lines, thereby preventing accidents [5].

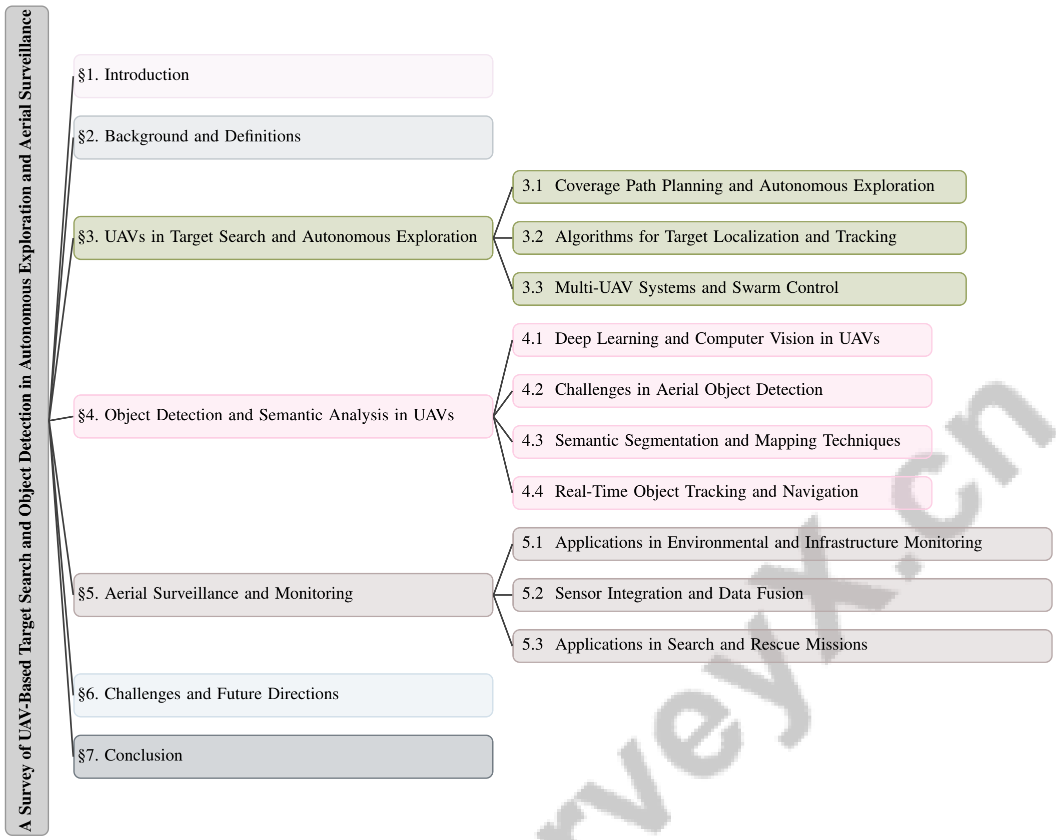


Figure 1: chapter structure

The emergence of Autonomous Aerial Vehicles (AAVs) has introduced new safety challenges regarding their interaction with the environment [6]. This necessitates robust frameworks for ensuring safe autonomous landings in dynamic settings where traditional methods are insufficient [7].

UAVs not only enhance efficiency and innovation across diverse applications but also highlight emerging challenges and research directions in UAV technology. Their ongoing evolution underscores their significance in modern applications, as they become increasingly integrated into various operational contexts [8].

1.2 Integration of UAVs in Specific Industries

The integration of UAVs across industries has been transformative, offering innovative solutions and improving operational efficiencies. In agriculture, UAVs are essential for monitoring crop health and facilitating precision agriculture, enabling accurate pesticide application and disease detection, which enhances both economic and ecological efficiency [9].

In public safety and surveillance, UAVs are employed for real-time monitoring and disaster management, gathering data from hazardous areas without risking human safety [10]. They have proven effective in search and rescue operations, covering large areas swiftly and providing critical information to ground teams [11]. The integration of multi-sensor approaches further enhances the detection, tracking, and localization of small UAVs, improving operational safety [12].

The logistics industry benefits significantly from UAV integration, particularly in last-mile delivery, which reduces delivery times and costs while extending accessibility to remote areas [13]. UAVs also contribute to traffic monitoring and management, fostering more efficient transportation networks [11].

In entertainment and media, UAVs have revolutionized cinematography by enabling automated aerial shots, democratizing access to drone-based filming through user-friendly tools that eliminate the

AI-generated, for reference only.

need for extensive training [14]. This innovation has expanded creative possibilities while reducing production costs.

The versatility of UAVs across sectors—such as agriculture, construction, surveillance, and disaster management—highlights their significant advantages, including enhanced operational efficiency, improved safety measures, and cost reductions. UAVs are increasingly employed for precision farming, real-time monitoring, and emergency response, leveraging their ability to access remote or hazardous areas and perform complex missions. Despite challenges like battery life and flight autonomy, advancements in UAV technology, including AI integration and tethered drones, are paving the way for further innovations [11, 15, 8, 13, 16]. As UAV technology continues to evolve, their applications are expected to expand, driving innovation and improving operational outcomes across diverse sectors.

1.3 Structure of the Survey

This survey provides a comprehensive overview of the integration of UAVs with advanced computer vision technologies across various applications. It is organized into several key sections, each focusing on different aspects of UAV deployment and technological advancements.

The introduction emphasizes the significance of UAVs in modern applications, highlighting their transformative role in industries such as agriculture, logistics, and public safety, alongside the integration of computer vision technologies that enhance UAV capabilities. The background and definitions section offers an overview of core concepts and technologies in UAV-based systems, defining key terms and discussing historical developments.

The survey examines UAV applications in target search and autonomous exploration, focusing on algorithms and strategies for efficient path planning and target localization. It highlights the optimization of flight path planning in search and rescue operations, emphasizing rapid coverage in critical situations. The development of the Obstacle-aware Adaptive Informative Path Planning (OA-IPP) algorithm, which utilizes a Gaussian Process-based model, is discussed for its ability to enhance search efficiency in cluttered environments by balancing information gain, sensor performance, and collision avoidance. Simulations demonstrate the superiority of these methods over existing planners, underscoring their practical applications [17, 18]. This is followed by a detailed examination of object detection and semantic analysis in UAVs, addressing challenges and solutions in aerial object detection through computer vision and machine learning techniques.

Subsequently, the applications of UAVs in aerial surveillance and monitoring are discussed, focusing on the integration of sensors and data fusion techniques. This section explores various real-world applications, including environmental monitoring, infrastructure integrity, and search and rescue missions.

The survey also examines the challenges and future directions of UAV-based systems, highlighting barriers such as battery endurance, flight autonomy, and regulatory frameworks. Ethical considerations related to UAV use in surveillance, precision agriculture, and disaster management are addressed, along with potential avenues for future research. Emphasis is placed on the need for advancements in AI integration, collision avoidance, and enhanced networking capabilities to overcome existing limitations and improve UAV operation effectiveness [11, 8, 19, 13, 10]. The conclusion summarizes key findings, emphasizing the importance of integrating UAVs with advanced computer vision technologies and the potential impact of future advancements.The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Core Concepts and Definitions

Unmanned Aerial Vehicles (UAVs), or drones, are sophisticated aircraft systems capable of autonomous operation, widely utilized in military, construction, aerial surveillance, and precision agriculture. They offer advantages such as extended flight durations and access to remote areas, but face challenges like limited battery life and flight autonomy. Efforts to enhance UAV autonomy include developing infrastructures for automated tasks, such as battery replacement, which aim to reduce human intervention and improve operational efficiency [8, 20]. UAVs are pivotal in modern applications, performing complex operations like target search, autonomous exploration, object detection, semantic analysis, and aerial surveillance.

Target search involves using advanced algorithms and high-resolution imagery to efficiently identify objects within a designated area [21]. Autonomous exploration allows UAVs to navigate uncharted environments, optimizing travel distance and information gain through integrated strategies and path planning.

Object detection and classification within a UAV's field of view are enhanced by computer vision and machine learning, analyzing imagery and video data. Semantic analysis enriches this process by interpreting contextual information, enabling UAVs to effectively interact with complex environments. In urban settings, semantic segmentation is critical for identifying infrastructure elements like buildings and roads, essential for urban planning and traffic monitoring. High-resolution aerial imagery from drones enhances this capability compared to traditional methods [22, 23, 24, 25, 26].

Aerial surveillance involves extensive area monitoring for intelligence or security, integrating multiple sensors and data fusion techniques for real-time situational awareness [3]. Computer vision is fundamental, enabling real-time processing of visual data for tasks like obstacle detection, avoidance, and 3D reconstructions [27].

Vehicle re-identification (ReID) from aerial imagery presents challenges due to the complexity of identifying vehicles from above, requiring advanced image processing techniques [28]. These core concepts—UAVs, target search, autonomous exploration, object detection, semantic analysis, aerial surveillance, and computer vision—are foundational to modern UAV applications, driving innovation and expanding capabilities across various sectors [8]. Understanding these terms is essential to appreciate the potential and challenges of UAV-based systems in contemporary contexts.

2.2 Technological Advancements in UAV Systems

The evolution of UAVs is significantly influenced by advancements in computer vision and machine learning, enhancing applications in agriculture and beyond [29]. These technologies have transformed UAVs from basic remote-controlled devices into autonomous systems capable of complex tasks. Vision-based technologies, crucial for applications like vehicle re-identification from aerial imagery, are advancing, though this area is underexplored due to limited datasets [28].

Innovations have addressed traditional UAV limitations, such as energy constraints and collision avoidance. Predictive angular potential field-based methods have been developed for obstacle avoidance in dynamic environments [30]. UAV architectures now include state estimation, coordination algorithms, and path planning, essential for effective swarm behavior and mission execution [31].

Despite advancements, UAV systems face challenges like limited battery life, restricted flight time, and cyber-attack vulnerabilities, necessitating improved charging solutions to extend operational duration [8]. The trajectory of UAV technological advancements is marked by ongoing innovation aimed at integrating cutting-edge technologies to address these challenges, enhancing autonomy, reliability, and operational efficiency. As these systems continue to evolve, they are expected to meet the increasing demands of modern applications, fostering further advancements in UAV capabilities.

In recent years, the development of Unmanned Aerial Vehicles (UAVs) has revolutionized various domains, particularly in target search and autonomous exploration. A comprehensive understanding of this evolution necessitates an examination of the underlying hierarchical structures that govern UAV operations. Figure 2 illustrates this hierarchical structure, outlining key areas such as coverage path planning, algorithms for target localization and tracking, and the dynamics of multi-UAV systems and swarm control. This figure categorizes advancements in algorithms and highlights enhancements, challenges, trajectory methods, techniques, strategies, and innovative methods. By visualizing these elements, the chart underscores the interconnectedness and comprehensive coverage of UAV applications across diverse fields, thereby enriching our understanding of their operational frameworks and potential future directions.

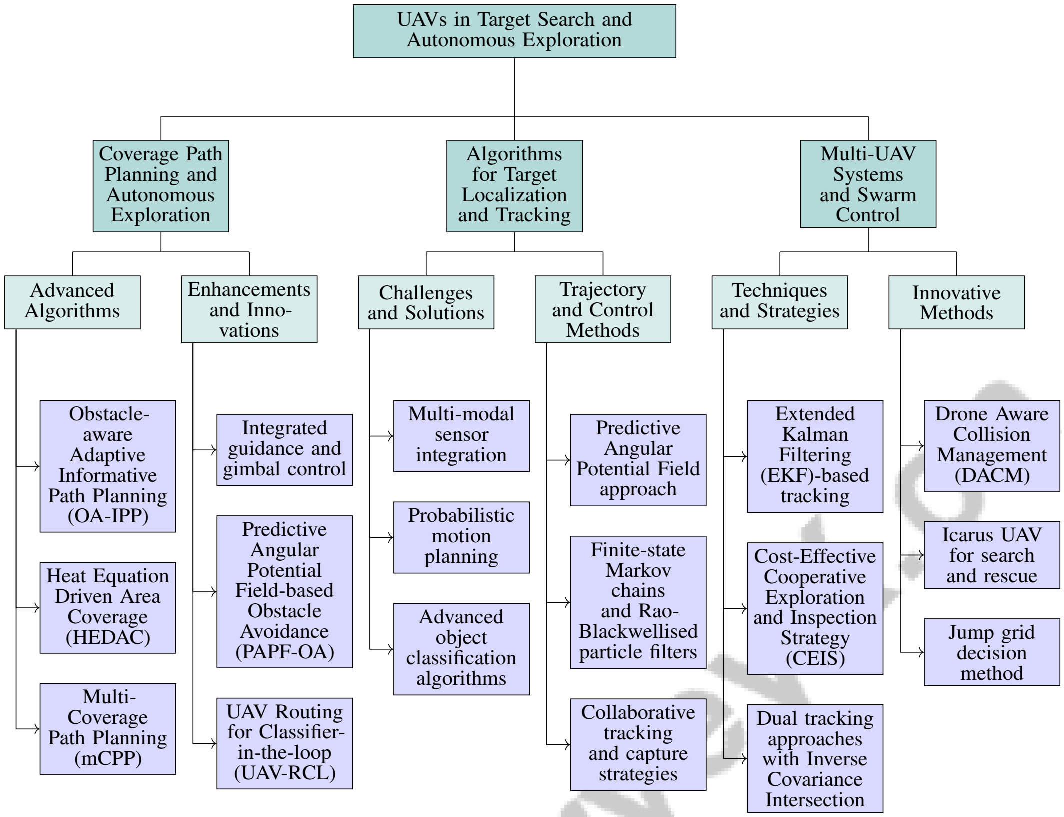


Figure 2: This figure illustrates the hierarchical structure of UAVs in target search and autonomous exploration, outlining key areas such as coverage path planning, algorithms for target localization and tracking, and multi-UAV systems and swarm control. The chart categorizes advancements in algorithms, enhancements, challenges, trajectory methods, techniques, strategies, and innovative methods, highlighting the interconnectedness and comprehensive coverage of UAV applications in various fields.

Method Name	Algorithmic Approaches	Application Scenarios	Performance Enhancements
CGF[32]	Octomap Approach	Gnss-denied Environments	Obstacle Avoidance
PCW[29]	Computer Vision Techniques	Precision Agriculture	Image Alignment
MTL-UAV[33]	Mtl-UAV	Urban Scene Understanding	Knowledge Sharing
RHF-SL-UAV[7]	Rhf-SL-UAV	Dynamic Environments	Real-time Obstacle
RSSU[4]	Semantic Segmentation	Radiation Search Operations	Obstacle Avoidance
PAPF-OA[30]	Papf-OA	Search And Rescue	Obstacle Avoidance
UAV-RCL[34]	Heuristic Approach	Real-world Surveillance	Task Allocation

Table 1: Overview of various UAV methods detailing their algorithmic approaches, application scenarios, and performance enhancements. This table highlights the diversity in methodologies and their specific applications in UAV operations, such as obstacle avoidance, precision agriculture, and urban scene understanding.

3 UAVs in Target Search and Autonomous Exploration

3.1 Coverage Path Planning and Autonomous Exploration

Coverage path planning (CPP) is critical for UAV operations, especially in applications like search and rescue, precision agriculture, and surveillance, where extensive area coverage is required. Advanced algorithms such as Obstacle-aware Adaptive Informative Path Planning (OA-IPP) and integrated guidance and gimbal control methods enhance UAV efficiency in complex terrains [35, 36, 37, 17, 18]. Innovations like the Heat Equation Driven Area Coverage (HEDAC) algorithm offer continuous, collision-free trajectories for multi-UAV operations in three-dimensional spaces [32]. The multi-Coverage Path Planning (mCPP) method integrates task allocation and path optimization, providing

AI-generated, for reference only.

a systematic approach to CPP [29]. Enhancements in cooperative area coverage performance are achieved by integrating information fusion, task assignment, and behavior decision-making frameworks [33]. Table 1 provides a comprehensive summary of different UAV methods, illustrating their algorithmic approaches, application scenarios, and performance enhancements within the context of coverage path planning and autonomous exploration.

Robustness-Driven Exploration (RDE) employs Probabilistic Metric Temporal Logic (P-MTL) for defining exploration constraints, focusing UAVs on maximizing information gain [7]. Image-based strategies like visual servo control enable complex tasks such as bridge painting through visual line tracking [4]. The Predictive Angular Potential Field-based Obstacle Avoidance (PAPF-OA) method improves obstacle avoidance using angular potential fields from LiDAR images [30]. UAV Routing for Classifier-in-the-loop (UAV-RCL) optimizes routes and dwell times at targets, refining path planning strategies [34].

These CPP and autonomous exploration advancements highlight UAV systems' potential for comprehensive coverage and efficient exploration, with future research focusing on lightweight energy sources and enhanced autonomy through improved navigation and localization algorithms [8].

3.2 Algorithms for Target Localization and Tracking

Developing algorithms for target localization and tracking is essential for UAVs operating in complex environments. Effective localization requires UAVs to interpret surroundings while navigating hazardous areas and making decisions based on uncertain sensory data. LS-Net exemplifies real-time power line detection in UAV imagery, enhancing tracking capabilities with single-shot line segmentation [5].

Challenges in autonomously detecting and tracking moving objects arise from environmental complexities like data noise and occlusion. Multi-modal sensor integration, probabilistic motion planning, and advanced object classification algorithms are vital for navigating dynamic conditions [38, 39, 40, 11]. A primary UAV with a 3D LiDAR sensor for global localization and a secondary UAV using visual data exemplifies effective multi-sensor integration for target tracking. View-centric multi-object tracking approaches address challenges in accurately tracking multiple objects from moving UAVs.

Trajectory prediction methods, such as the Predictive Angular Potential Field approach, enhance localization and tracking by determining appropriate velocities for dynamic target pursuit. Robust flight controllers for UAVs tracking ground moving targets (GMT) with unknown maneuvers utilize techniques like finite-state Markov chains and Rao-Blackwellised particle filters [41, 42, 43, 44, 45]. Integrating trajectory planning and motion prediction methods is crucial for navigating complex environments and ensuring successful tracking amidst uncertainties.

Autonomous targeting algorithms for quadrotors enhance airspace safety by focusing on semi-stationary and moving aerial objects with limited prior knowledge. Collaborative tracking and capture strategies involve methodologies to minimize UAV risks, with multiple UAVs enhancing target capture through visual feedback [15, 46, 47].

Optimizing UAV routing involves determining the most efficient sequence for visiting multiple targets and ideal dwell times to maximize information gain, facilitated by mixed-integer linear programming and heuristic algorithms [43, 34]. Effective identification mechanisms in multi-UAV systems are crucial for motion coordination and collision avoidance, emphasizing robust communication protocols.

Advancements in target localization and tracking algorithms broaden UAV applicability across diverse domains. Future research should focus on integrating multi-modal sensor data—such as stereo vision, LiDAR, and thermal imaging—with adaptive algorithms that dynamically respond to changing conditions, enhancing UAV-based tracking systems' robustness and reliability [12, 48, 39, 49].

3.3 Multi-UAV Systems and Swarm Control

Multi-UAV systems and swarm control techniques significantly enhance search and exploration capabilities, improving efficiency and robustness across applications. These systems leverage collective UAV behavior to execute complex tasks, such as extensive area coverage and precise target localization, reducing operator fatigue [50, 51].

Integration of Extended Kalman Filtering (EKF)-based tracking schemes optimizes UAV trajectories, minimizing predicted posterior Cramér-Rao bounds (PCRBs) for position and velocity estimation, crucial for precise navigation [31]. Control barrier functions (CBFs) ensure safety and collision avoidance during target tracking in cluttered environments.

The Cost-Effective Cooperative Exploration and Inspection Strategy (CEIS) optimizes task assignments for heterogeneous drone teams, using voxel maps for effective pathfinding and enabling comprehensive 3D surface coverage without precise prior environmental knowledge. CEIS enhances cooperative aerial inspections through rule-based path-planning methods and specialized drone teams for mapping and inspection [52, 53, 54, 35]. The Cooperative Aerial Robots Inspection (CARI) methodology exemplifies this by utilizing heterogeneous UAVs for cooperative mapping and optimized inspection paths.

Dual tracking approaches in dynamic environments, integrating simultaneous scan frequencies using the Inverse Covariance Intersection method, improve tracking accuracy and persistence. Communication-efficient strategies are essential for coordinating multiple UAVs, minimizing communication overhead while ensuring effective task allocation.

Advanced collision management techniques, such as the Drone Aware Collision Management (DACM), employ reactive geometric conflict detection and resolution methods to enhance collision avoidance in autonomous operations. DACM integrates electronic conspicuity information, enabling UAVs to effectively detect and respond to potential mid-air collisions [55, 56, 2, 57]. Predictive frameworks with probabilistic bounds on tracking errors allow real-time UAV coordination, ensuring performance in cooperative tasks like wildfire monitoring.

The Icarus UAV, designed for search and rescue operations, illustrates multi-UAV systems' practical applications in critical missions. Future research should integrate advanced algorithms and communication strategies, particularly developing specialized datasets like the Combination to Application (C2A) dataset, to improve human detection in disaster scenarios. This approach optimizes machine learning models' performance in diverse contexts, addressing existing challenges and leveraging AI capabilities in UAV networks [58, 34, 11, 19, 48].

Innovative methods, such as a jump grid decision method, allow UAVs to navigate non-adjacent grids while respecting maneuverability constraints and optimizing search efficiency. The gradient-based control law helps UAVs reach locally optimal configurations while adhering to altitude limits. Multi-UAV collaborative 3D object detection enhances search capabilities, and dynamically adjusting flight strategies based on real-time detection improves operational efficiency. A networked swarm of defense UAVs can self-organize to form a protective barrier around a mobile UAV, efficiently escorting it outside the flight zone [56]. The multi-layered architecture for mission-oriented miniature fixed-wing UAV swarms addresses scalability and versatility challenges [59]. The mCPP method enhances coverage efficiency, reduces mission duration, and effectively manages complex-shaped regions of interest (ROIs) with no-fly zones (NFZs). By combining reinforcement learning with path planning, this method optimizes Quality-of-Service (QoS) while considering user demand and environmental risks. The complexities of cooperative area coverage and target tracking using multi-UAV systems highlight the need for integrating noise reduction techniques, sound source localization methods, and evaluation metrics with UAV technology [46].

4 Object Detection and Semantic Analysis in UAVs

4.1 Deep Learning and Computer Vision in UAVs

Advancements in deep learning and computer vision have greatly enhanced UAV capabilities, enabling precise operations across diverse applications. Models like YOLOv9, Faster R-CNN, and Cascade R-CNN have significantly improved object detection, particularly with datasets such as C2A, demonstrating substantial progress in UAV research [48]. These models leverage state-of-the-art techniques to enhance detection accuracy and speed, which are crucial for real-time applications.

HomView-MOT, utilizing Homographic Matching and View-Centric concepts, addresses multi-object tracking complexities from aerial platforms. Its Fast Homography Estimation (FHE) algorithm and Homographic Matching Filter (HMF) enhance tracking accuracy by aligning object bounding boxes across frames onto a common view plane [60]. The Fast Object Localization and Tracking (FOLT) method, employing a Kalman filter, further demonstrates precision in real-time tracking [61].

Large, high-resolution datasets with annotations for semantic segmentation and depth estimation have spurred innovations in UAV capabilities [33]. These datasets aid in developing robust machine learning models for object detection in UAV images, ensuring performance across various imaging conditions [62]. LS-Net exemplifies deep learning's role in real-time line segment detection, highlighting computer vision technologies' significance in UAV operations [5].

In agriculture, computer vision aids in crop identification and individualization, reflecting deep learning advancements in monitoring [29]. Integrating LiDAR sensor data enhances real-time flight direction computations, showcasing progress in UAV computer vision technologies [30].

These advancements underscore deep learning and computer vision's transformative impact on UAV applications, offering innovative solutions that enhance autonomy and effectiveness in surveillance, agriculture, and environmental monitoring. As research progresses, UAV technology is expected to bolster capabilities in civil applications like real-time monitoring and infrastructure inspection, offering high-quality data acquisition at lower costs compared to traditional methods while addressing challenges such as collision avoidance and security. The UAV market, projected to exceed $45 billion, ispoisedforexpansionacrossvarioussectors, thoughconcernsaboutmisusenecessitateongoingforensicanal$
15].

4.2 Challenges in Aerial Object Detection

Aerial object detection is challenged by real-world complexities and technological limitations. Variability in object features, scales, and orientations complicates detection [63]. Maritime environments further exacerbate detection difficulties due to feature diversity and environmental variability [63].

Real-time processing requirements present additional hurdles, as UAVs' ego-noise and wind noise impact audio-based detection systems [3]. The computational demands of CNNs, coupled with the need for low latency and minimal power consumption, pose significant challenges for resource-constrained UAVs [61].

Current detection methods, both anchor-based and anchor-free, struggle to generalize across diverse scales and orientations in aerial imagery, leading to inference errors [62]. The reliance on cooperative signals for threat detection limits effectiveness, as such signals are not always available for threats like rogue drones [2].

Semantic segmentation in drone videos faces challenges primarily due to costly and time-consuming pixel-wise annotations [24]. The scarcity of relevant datasets for specific applications, such as maritime UAV object detection, further restricts algorithm development [63].

Addressing these challenges requires continuous advancements in algorithm development, sensor integration, and data processing techniques. Enhancing UAV systems' robustness and efficiency through specialized datasets and advanced object detection models can significantly improve reliability in complex aerial environments. Such improvements facilitate applications in critical areas like surveillance and disaster management, addressing challenges posed by diverse backgrounds and weather conditions, ultimately leading to more reliable AI-assisted interventions in search and rescue operations and other UAV applications [48, 64, 65].

4.3 Semantic Segmentation and Mapping Techniques

Advancements in semantic segmentation and mapping techniques in UAV systems are driven by multi-task networks and real-time data processing capabilities. Integrating pixel-wise semantic segmentation and object detection from multiple sensors produces comprehensive semantic representations in real time, enhancing UAV situational awareness and decision-making in complex environments [66].

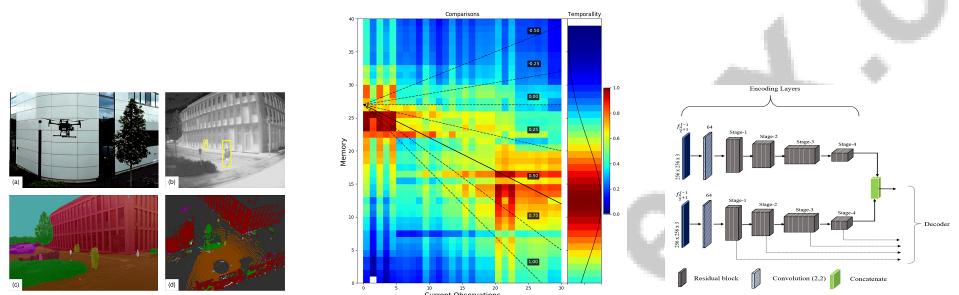
Encoder-focused multi-task networks have improved semantic segmentation performance by sharing learned features between tasks, achieving superior results compared to single-task approaches [67]. This innovation optimizes computational resources and enhances segmentation and mapping accuracy.

UVid-Net exemplifies advancements in semantic segmentation tailored for UAV video data, employing a modified encoder-decoder structure that processes consecutive frames together to improve segmentation accuracy through temporal information utilization [22].

Evaluating semantic segmentation models requires robust metrics, with the F-measure preferred for balancing precision and recall across diverse object categories, ensuring reliable scene interpretation by UAV systems [24].

Synthetic data from game engines has introduced a novel benchmark for validating object detection in UAV systems, allowing controlled imaging parameter variations and offering a reproducible alternative to traditional data collection methods, facilitating robust algorithm development [62].

These advancements highlight the evolution of semantic segmentation and mapping techniques in UAV systems, emphasizing multi-sensor data integration and advanced machine learning applications. As research progresses, AI integration with UAVs is expected to enhance capabilities across applications like surveillance, environmental monitoring, and disaster management, improving operational efficiency and effectiveness. Ongoing developments aim to address limitations in battery endurance and flight autonomy, expanding UAV missions' operational range and duration. This technological convergence drives innovation within the UAV industry while raising important considerations regarding ethical deployment, safety regulations, and potential misuse in criminal activities [15, 8, 11].



(a) Urban Surveillance and Mapping Using Drones and Thermal Imaging[66]

(b) The image is a heatmap representing the relationship between "Comparisons" and "Temporallity" in a dataset.[68]

(c) Residual Block Based 4-Stage U-Net for Medical Image Segmentation[22]

Figure 3: Examples of Semantic Segmentation and Mapping Techniques

As shown in Figure 3, the integration of object detection and semantic analysis in UAVs has been significantly enhanced through semantic segmentation and mapping techniques. This is exemplified in various scenarios, such as urban surveillance and mapping with drones and thermal imaging, where drones navigate urban environments to capture thermal images for detecting and tracking individuals while overlaying 3D models for comprehensive spatial understanding. Another application involves heatmaps illustrating the relationship between "Comparisons" and "Temporality" within datasets, providing insights into data patterns through color-coded matrices. Additionally, the deployment of a Residual Block Based 4-Stage U-Net architecture showcases convolutional neural networks' potential in medical image segmentation, effectively managing spatial resolution challenges for precise and reliable analysis. These examples underscore the transformative impact of semantic segmentation and mapping techniques in enhancing UAV capabilities across various domains [66, 68, 22].

4.4 Real-Time Object Tracking and Navigation

Real-time object tracking and navigation are pivotal for enhancing UAV operational capabilities, enabling efficient monitoring and interaction with dynamic environments. Recent advancements have focused on optimizing tracking performance and navigation accuracy through innovative methodologies. The Butterfly Detector exemplifies an anchor-free object detection method utilizing composite butterfly fields to predict object attributes in aerial images, thereby improving detection accuracy in complex scenarios [23].

The DFPN architecture achieves a mean Average Precision of 30.6 with an inference speed of 14 frames per second, demonstrating effectiveness for real-time object detection on UAVs while maintaining memory efficiency [64]. The integration of real-time video stabilization algorithms addresses atmospheric turbulence and jittery flight control challenges, significantly enhancing video quality and tracking reliability [69].

The MAT-Fly platform simulates UAV dynamics and implements visual servoing techniques, facilitating robust object tracking system development [70]. This capability is complemented by edge processing, which has proven efficient and suitable for real-time applications, paving the way for future research on complex scenarios [71].

Real-time object tracking is further enhanced by streaming visual feedback from UAVs, improving situational awareness during tele-operation tasks [72]. Wu et al. propose a method achieving superior performance in real-time object localization and tracking, offering faster processing and better accuracy, although challenges with occlusions persist [61].

Detection accuracy is influenced by camera position and illumination, with models like RetinaNet generally outperforming others under varying conditions [62]. These advancements underscore the ongoing evolution of UAV systems, focusing on enhancing precision, efficiency, and adaptability in diverse operational contexts. As research progresses, these technologies are expected to further improve UAV capabilities, providing innovative solutions for real-time object tracking and navigation across various applications.

5 Aerial Surveillance and Monitoring

The integration of Unmanned Aerial Vehicles (UAVs) into aerial surveillance and monitoring has significantly advanced environmental and infrastructure management. UAVs provide high-resolution data and real-time analytics, enhancing monitoring strategies. This section delves into UAV applications in these critical areas.

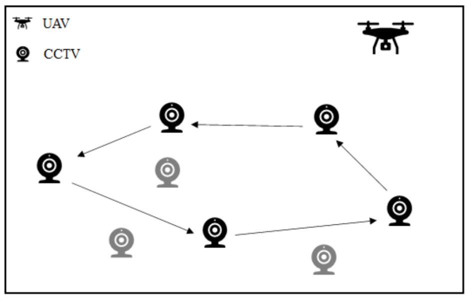
5.1 Applications in Environmental and Infrastructure Monitoring

UAVs are pivotal in environmental and infrastructure monitoring due to their versatility and ability to capture high-resolution data over large areas. They enable dynamic coverage and real-time data acquisition, crucial for managing natural and built environments. For instance, UAV deployment optimizes coverage and resource allocation in the Israeli transportation network, enhancing maintenance strategies [73]. The UAVid dataset aids urban planning and traffic monitoring by providing comprehensive semantic segmentation data [25]. In environmental contexts, UAVs facilitate wildlife observation and habitat assessment, offering insights into wildlife distribution and behavior through geo-referenced imagery [74].

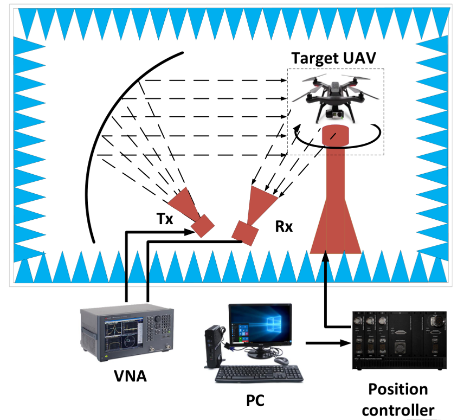
In maritime surveillance, the MS2ship dataset underscores UAVs' role in monitoring marine traffic, where advanced detection algorithms track vessels, contributing to maritime safety and environmental protection [63]. Cost-effective cooperative exploration and inspection strategies further enhance UAV applications in infrastructure monitoring by enabling operations without prior environmental knowledge, thereby improving inspection performance [53]. These advancements ensure comprehensive and timely assessments of infrastructure integrity, enhancing safety and reliability.

UAV integration in environmental and infrastructure monitoring not only improves data collection and analysis but also enhances safety and operational efficiency. Developing frameworks for UAV safety and collision avoidance ensures reliable operations across diverse applications [2]. As UAV technology evolves, its applications in monitoring are expected to expand, offering innovative solutions for sustainable management.

As depicted in Figure 4, modern aerial surveillance systems enhance observational capabilities through UAV and radar technologies. One approach combines UAVs with CCTV cameras to create a comprehensive surveillance network for real-time monitoring. The strategic positioning of UAVs allows for dynamic oversight and flexibility in capturing diverse angles, augmenting overall coverage. Another approach involves radar systems configured to detect and track UAVs, employing sophisticated antenna arrays to monitor UAV movements within designated airspaces. These systems exemplify the innovative application of aerial surveillance technology in environmental and infrastructure monitoring, enhancing precision and efficiency in data collection and analysis [75, 76].



(a) UAV and CCTV Surveillance System[75]



(b) A diagram illustrating a radar system for detecting and tracking a target unmanned aerial vehicle (UAV)[76]

Figure 4: Examples of Applications in Environmental and Infrastructure Monitoring

5.2 Sensor Integration and Data Fusion

The integration of diverse sensor technologies and advanced data fusion techniques significantly enhances UAV surveillance capabilities. This multifaceted approach enables UAVs to perform intricate monitoring tasks with improved accuracy and reliability, crucial for applications in search and rescue, disaster management, and security surveillance. Leveraging artificial intelligence and specialized datasets, UAVs effectively detect and classify objects in various environments, addressing privacy and national security challenges [11, 15, 48, 77, 76].

Optimization strategies, such as the GD-Cover method, use geometric reasoning and statistical model checking to analyze and optimize sensor placements for UAV localization in complex 3D environments, ensuring fault tolerance and quality guarantees [78]. This strategic positioning allows UAVs to achieve comprehensive coverage and maintain operational efficiency in challenging terrains.

Data fusion is further enhanced through immersive digital technologies like Digital Twins (DT) and Extended Reality (XR), which synthesize data from various sources to improve situational awareness and decision-making capabilities in UAV operations [79]. This integration allows operators to visualize complex data and make informed decisions in real-time, enhancing UAV surveillance performance.

Multi-agent deep reinforcement learning (MADRL) facilitates autonomous communication and coordination among UAVs, enabling collaborative efforts that optimize surveillance outcomes through shared sensor data [80]. Progressive representation learning techniques capture both local spatial information and global context, refining sensor data processing and enhancing UAV surveillance accuracy [81].

Datasets merging multiple publicly available sources, including images with specific backgrounds and synthetic artifacts, are crucial for advancing sensor integration and data fusion [65]. These datasets provide valuable training data for developing robust algorithms capable of handling diverse environmental conditions.

The integration of advanced sensors and data fusion techniques significantly enhances UAV surveillance capabilities, enabling them to perform complex monitoring tasks with increased precision and reliability. As research progresses, the integration of artificial intelligence with UAVs is expected to catalyze innovations in surveillance applications, yielding more sophisticated solutions for diverse operational contexts while addressing critical challenges related to battery endurance and regulatory frameworks [8, 47, 15, 11].

5.3 Applications in Search and Rescue Missions

UAVs are vital in search and rescue (SAR) missions, providing critical support in environments where traditional methods face challenges. Their integration enhances the ability to locate and assist individuals in distress, particularly in areas with unreliable GPS signals. For instance, Q-learning-based SAR operations enable UAVs to effectively locate victims in complex environments [82]. The Icarus UAV exemplifies UAV contributions to SAR missions, significantly improving aerial coverage and response times, thereby enhancing the efficiency of rescue operations [83]. Additionally, active perception systems in UAVs allow for dynamic landings on water surfaces, achieving high success rates in real-world applications [84].

In complex SAR scenarios, the NOPP algorithm efficiently generates feasible solutions for UAV path planning, managing scenarios with up to 10,000 cells while maintaining a low optimality gap [18]. This capability is critical for optimizing UAV operations in demanding environments, ensuring comprehensive area coverage and timely responses.

Multi-UAV systems in cooperative SAR missions significantly enhance operational capabilities by providing timely and precise information to human responders. This advanced approach improves coordination and effectiveness during rescue efforts, with UAVs strategically deployed to cover vast areas quickly while maintaining high victim detection rates. Recent advancements, such as the development of specialized human detection datasets like the Combination to Application (C2A) dataset, optimize detection model performance in these missions. Simulation analyses also highlight the importance of effective flight planning and exploration strategies, ensuring UAVs can efficiently scan disaster-affected areas and minimize false negatives, thereby strengthening AI-assisted interventions in SAR operations [48, 44].

Despite these advancements, challenges remain in efficiently navigating and avoiding obstacles during SAR tasks, which is essential for improving UAV performance in real-world operations [85]. The development of vision-based autonomous navigation systems has demonstrated significant improvements in UAVs' ability to navigate and land autonomously in disaster-struck environments, further enhancing SAR efficiency [86].

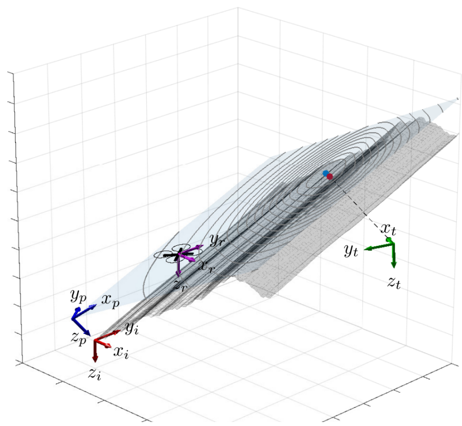
UAVs are increasingly vital in search and rescue missions, offering innovative solutions that enhance the speed, coverage, and effectiveness of emergency response efforts. As UAV technology continues to evolve, their applications in SAR missions are anticipated to broaden significantly, improving operational capabilities through advanced flight planning, enhanced human detection datasets, and AI-assisted interventions. These developments aim to optimize UAV efficiency in locating victims swiftly while minimizing false negatives, ultimately providing more effective support in critical emergency situations [48, 8, 44].

As shown in Figure 5, aerial surveillance technologies in search and rescue missions have become increasingly significant, transforming disaster management approaches. The first image illustrates a 3D plot of a robot's trajectory, highlighting navigational paths through colored lines representing different time intervals, emphasizing UAVs' potential in mapping and assessing disaster-stricken areas. The second image captures disaster scenes and human interactions, showcasing various scenarios such as building collapses and overturned vehicles, with red boxes around individuals emphasizing the dynamics of search and rescue missions. Together, these examples illustrate the multifaceted applications of aerial surveillance in enhancing the effectiveness and efficiency of rescue efforts [87, 48].

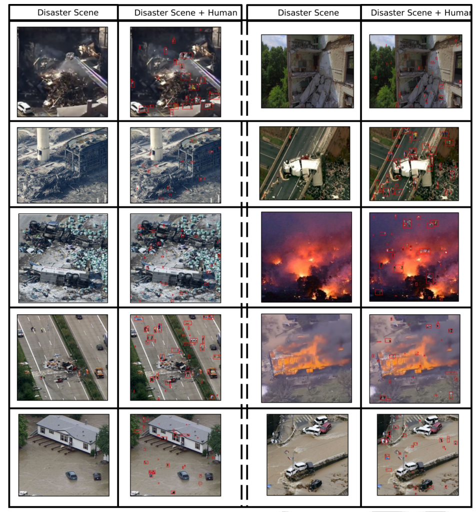
6 Challenges and Future Directions

6.1 Challenges in UAV Deployment for Surveillance

Deploying Unmanned Aerial Vehicles (UAVs) for surveillance involves several operational and technological hurdles. A significant operational challenge is the precise localization of targets over long distances, often hindered by monocular vision systems that can cause depth perception errors, especially in dynamic environments like facade inspections [60, 27]. Technologically, reliance on LiDAR for self-localization and inter-UAV positioning is problematic in cluttered environments, leading to potential localization errors [32]. Additionally, RF-based localization techniques are susceptible to electromagnetic interference and are ineffective in GNSS-denied areas [59].



(a) 3D Plot of a Robot's Trajectory and Surrounding Environment[87]



(b) Disaster Scene and Human Interaction[48]

Figure 5: Examples of Applications in Search and Rescue Missions

Identifying safe landing zones in dynamic environments is another critical issue, as current methods often fail under such conditions, increasing safety risks during UAV landings [7]. Furthermore, global navigation planning for obstacle avoidance frequently lacks adaptability to newly detected obstacles, heightening collision risks and reducing operational efficiency [30].

In search and rescue missions, UAVs grapple with sound localization challenges, as many studies rely on simulated datasets that may not accurately reflect real-world scenarios [3]. This underscores the need for adaptable data collection methodologies to ensure UAV reliability across diverse environments. In agriculture, overlapping neighboring plants complicate complex visual data processing from UAV imagery, impeding effective information extraction [29]. Moreover, existing datasets often focus on specific fault types, limiting their practical applicability [6].

Addressing these challenges necessitates advancements in sensor technologies, localization techniques, and algorithm development to enhance UAV robustness and reliability in surveillance applications. Continuous research and innovation are crucial for overcoming these hurdles, enabling effective UAV deployment across various surveillance contexts, despite ongoing issues with battery endurance and security vulnerabilities [8].

6.2 Ethical and Regulatory Challenges

The societal integration of Unmanned Aerial Vehicles (UAVs) presents significant ethical and regulatory challenges. Privacy is a primary ethical concern, as UAVs' ability to capture high-resolution images and videos may infringe on privacy rights, raising critical questions about consent and oversight, especially given their potential misuse for unauthorized surveillance and data collection [11, 88, 15, 13, 47].

Regulatory frameworks struggle to keep pace with UAV technological advancements, with significant variation across jurisdictions complicating compliance for operators. The lack of standardized guidelines for UAV forensic investigations can lead to confusion and non-compliance, raising concerns about unauthorized operations and potential misuse in recreational and commercial sectors [15, 47]. Balancing innovation with public safety and privacy is essential to mitigate UAV-related risks.

Current regulatory approaches often rely on theoretical probabilities, such as Bayesian analysis, revealing limitations due to insufficient concrete data on UAV crashes [89]. This highlights the need for comprehensive data collection and analysis to inform robust regulatory frameworks. Additionally, UAVs' increasing use in surveillance and military operations poses ethical implications, including facilitating unlawful activities like drug trafficking, which raises questions about national security and responsible technology deployment [11, 88, 8, 15, 47].

As UAV technology evolves, regulatory bodies must develop adaptive frameworks accommodating new capabilities and applications. This includes establishing clear guidelines for data collection and usage, ensuring transparency in UAV operations, and fostering public trust through accountability measures. Effectively addressing the ethical and regulatory challenges associated with UAVs can maximize their benefits while protecting privacy rights and ensuring public safety [11, 15, 13, 16, 47].

6.3 Future Research Directions

Future research in Unmanned Aerial Vehicle (UAV) systems aims to address current challenges and enhance operational capabilities through innovative directions. A critical focus will be improving the efficiency and robustness of the Rao-Blackwellized Particle Filter (RBPF) by integrating advanced estimation techniques or machine learning approaches, which could significantly enhance UAV performance in dynamic environments [45]. Additionally, optimizing task allocation among UAVs for capturing high-speed and maneuverable targets will enhance overall system performance in collaborative tracking and capture missions [46].

Integrating synthetic data generation with real-world data is another promising area, as it could improve model robustness and object detection capabilities in UAV systems [62]. Future research should explore further refinements in synthetic data generation to ensure models are better equipped to handle real-world complexities.

Enhancing the adaptability of line segment detection methods like LS-Net to diverse environments is also crucial, including exploring applications in detecting other linear infrastructures, thereby broadening UAV applications in infrastructure monitoring [5]. Moreover, integrating multi- or hyperspectral data into UAV methods is essential for advancing agricultural applications, particularly in plant detection and analysis [29].

Developing advanced localization techniques, enhancing communication frameworks, and exploring decentralized control methods will be vital for improving swarm autonomy and effectiveness [31]. Additionally, innovative solutions to enhance UAV battery life and security measures, as well as integrating UAVs with emerging technologies like 5G and IoT, will expand their operational capabilities [8].

Exploring these research directions is anticipated to catalyze substantial technological advancements in UAV systems, effectively tackling existing challenges—such as battery endurance, collision avoidance, and networking security—while broadening UAV applicability across various operational contexts, including civil infrastructure, precision agriculture, and disaster management. By integrating artificial intelligence and addressing the unique challenges of UAV deployment, these advancements promise to enhance the efficiency, safety, and versatility of UAV applications in both civilian and military domains [13, 8, 19, 11].

7 Conclusion

This survey demonstrates the profound impact of integrating Unmanned Aerial Vehicles (UAVs) with advanced computer vision technologies, significantly enhancing their utility across various sectors. By leveraging AI and computer vision, UAVs have achieved remarkable improvements in capabilities such as precise target search, autonomous exploration, and efficient object detection. These enhancements are crucial for diverse applications, including agriculture and counterterrorism. The study underscores AI's critical role in advancing UAV functionalities and stresses the importance of interdisciplinary efforts to address regulatory and ethical challenges.

Recent developments in deep learning and computer vision have fostered the emergence of autonomous UAV systems capable of executing complex tasks, such as non-destructive inspections of rotating wind turbines and real-time human action recognition. These technological strides have facilitated the successful deployment of UAVs in dynamic settings, ensuring safe navigation and effective 3D reconstruction, particularly in challenging environments like tunnel inspections. Moreover, the integration of AI within UAV networks has catalyzed innovative applications in disaster management and surveillance, markedly enhancing operational efficiency.

The survey further highlights the potential of UAV forensics in aiding investigations related to UAV incidents, emphasizing the necessity for continued research and development in this rapidly advancing field. As UAV technology evolves, future research should focus on optimizing energy efficiency, enhancing swarm autonomy, and bolstering security measures. These advancements are expected to drive further innovations, expanding UAV applications and maximizing their impact across a wide range of operational contexts.

References

[1] Z. Jiang and G. Song. A deep reinforcement learning strategy for uav autonomous landing on a platform, 2022.

[2] Vasileios Karampinis, Anastasios Arsenos, Orfeas Filippopoulos, Evangelos Petrongonas, Christos Skliros, Dimitrios Kollias, Stefanos Kollias, and Athanasios Voulodimos. Ensuring uav safety: A vision-only and real-time framework for collision avoidance through object detection, tracking, and distance estimation, 2024.

[3] Antoine Deleforge, Diego Di Carlo, Martin Strauss, Romain Serizel, and Lucio Marcenaro. Audio-based search and rescue with a drone: Highlights from the ieee signal processing cup 2019 student competition, 2019.

[4] Gordon Christie, Adam Shoemaker, Kevin Kochersberger, Pratap Tokekar, Lance McLean, and Alexander Leonessa. Radiation search operations using scene understanding with autonomous uav and ugv, 2016.

[5] Van Nhan Nguyen, Robert Jenssen, and Davide Roverso. Ls-net: Fast single-shot line-segment detector, 2020.

[6] Azarakhsh Keipour, Mohammadreza Mousaei, and Sebastian Scherer. Alfa: A dataset for uav fault and anomaly detection, 2020.

[7] Jaskirat Singh, Neel Adwani, Harikumar Kandath, and K. Madhava Krishna. Real-time heuristic framework for safe landing of uavs in dynamic scenarios, 2022.

[8] Review.

[9] A review of applications and pot.

[10] Bander Alzahrani, Omar Sami Oubbati, Ahmed Barnawi, Mohammed Atiquzzaman, and Daniyal Alghazzawi. Uav assistance paradigm: State-of-the-art in applications and challenges. *Journal of Network and Computer Applications*, 166:102706, 2020.

[11] Osim Kumar Pal, Md Sakib Hossain Shovon, M. F. Mridha, and Jungpil Shin. A comprehensive review of ai-enabled unmanned aerial vehicle: Trends, vision , and challenges, 2023.

[12] Zhibo Zhang, Chen Zeng, Maulikkumar Dhameliya, Souma Chowdhury, and Rahul Rai. Deep learning based multi-modal sensing for tracking and state extraction of small quadcopters, 2020.

[13] Hazim Shakhatreh, Ahmad Sawalmeh, Ala Al-Fuqaha, Zuochao Dou, Eyad Almaita, Issa Khalil, Noor Shamsiah Othman, Abdallah Khreishah, and Mohsen Guizani. Unmanned aerial vehicles: A survey on civil applications and key research challenges, 2018.

[14] Quentin Galvane, Julien Fleureau, Francois-Louis Tariolle, and Philippe Guillotel. Automated cinematography with unmanned aerial vehicles. *arXiv preprint arXiv:1712.04353*, 2017.

[15] Tanay Kumar and Mangal Kothari. Insights to the forensic investigation of a custom built uav, 2023.

[16] Samuel O. Folorunsho and William R. Norris. Redefining aerial innovation: Autonomous tethered drones as a solution to battery life and data latency challenges, 2024.

[17] Ajith Anil Meera, Marija Popovic, Alexander Millane, and Roland Siegwart. Obstacle-aware adaptive informative path planning for uav-based target search, 2019.

[18] Sina Kazemdehbashi and Yanchao Liu. An exact coverage path planning algorithm for uav-based search and rescue operations, 2024.

[19] Meshari Aljohani, Ravi Mukkamalai, and Stephen Olariu. Autonomous strike uavs for counterterrorism missions: Challenges and preliminary solutions, 2024.

[20] Michael Rosenberg, John Henry Burns, Deeraj Nagothu, and Yu Chen. Enabling continuous operations for uavs with an autonomous service network infrastructure, 2020.

[21] Changye Yang, Sriram Baireddy, Enyu Cai, Melba Crawford, and Edward J. Delp. Field-based plot extraction using uav rgb images, 2021.

[22] Girisha S, Ujjwal Verma, Manohara Pai M M, and Radhika Pai. Uvid-net: Enhanced semantic segmentation of uav aerial videos by embedding temporal information, 2021.

[23] George Adaimi, Sven Kreiss, and Alexandre Alahi. Perceiving traffic from aerial images, 2020.

[24] Alina Marcu, Dragos Costea, Vlad Licaret, and Marius Leordeanu. Towards automatic annotation for semantic segmentation in drone videos, 2019.

[25] Ye Lyu, George Vosselman, Guisong Xia, Alper Yilmaz, and Michael Ying Yang. Uavid: A semantic segmentation dataset for uav imagery, 2020.

[26] Meida Chen, Andrew Feng, Kyle McCullough, Pratusha Bhuvana Prasad, Ryan McAlinden, and Lucio Soibelman. Semantic segmentation and data fusion of microsoft bing 3d cities and small uav-based photogrammetric data, 2020.

[27] Yang Lyu, Muqing Cao, Shenghai Yuan, and Lihua Xie. Vision based autonomous uav plane estimation and following for building inspection, 2021.

[28] Peng Wang, Bingliang Jiao, Lu Yang, Yifei Yang, Shizhou Zhang, Wei Wei, and Yanning Zhang. Vehicle re-identification in aerial imagery: Dataset and approach, 2019.

[29] Maurice Günder, Facundo R. Ispizua Yamati, Jana Kierdorf, Ribana Roscher, Anne-Katrin Mahlein, and Christian Bauckhage. Agricultural plant cataloging and establishment of a data framework from uav-based crop images by computer vision, 2022.

[30] Daniel Schleich and Sven Behnke. Predictive angular potential field-based obstacle avoidance for dynamic uav flights, 2022.

[31] Mohamed Abdelkader, Samet Güler, Hassan Jaleel, and Jeff S Shamma. Aerial swarms: Recent applications and challenges. *Current robotics reports*, 2:309–320, 2021.

[32] Václav Pritzl, Matouš Vrba, Yurii Stasinchuk, Vít Krátký, Jiří Horyna, Petr Štěpán, and Martin Saska. Drones guiding drones: Cooperative navigation of a less-equipped micro aerial vehicle in cluttered environments, 2024.

[33] Mohammad R. Bayanlou and Mehdi Khoshboresh-Masouleh. Multi-task learning from fixed-wing uav images for 2d/3d city modeling, 2021.

[34] Deepak Prakash Kumar, Pranav Rajbhandari, Loy McGuire, Swaroop Darbha, and Donald Sofge. Uav routing for enhancing the performance of a classifier-in-the-loop, 2023.

[35] Savvas D. Apostolidis, Pavlos Ch. Kapoutsis, Athanasios Ch. Kapoutsis, and Elias B. Kosmatopoulos. Cooperative multi-uav coverage mission planning platform for remote sensing applications, 2022.

[36] Savvas Papaioannou, Panayiotis Kolios, Theocharis Theocharides, Christos G. Panayiotou, and Marios M. Polycarpou. Integrated guidance and gimbal control for coverage planning with visibility constraints, 2023.

[37] Savvas Papaioannou, Panayiotis Kolios, Theocharis Theocharides, Christos G. Panayiotou, and Marios M. Polycarpou. 3d trajectory planning for uav-based search missions: An integrated assessment and search planning approach, 2023.

[38] A. Huzeyfe Demir, Berke Yavas, Mehmet Yazici, Dogukan Aksu, and M. Ali Aydin. Object detection and tracking with autonomous uav, 2022.

[39] Tianchen Deng, Yi Zhou, Wenhua Wu, Mingrui Li, Jingwei Huang, Shuhong Liu, Yanzeng Song, Hao Zuo, Yanbo Wang, Yutao Yue, Hesheng Wang, and Weidong Chen. Multi-modal uav detection, classification and tracking algorithm – technical report for cvpr 2024 ug2 challenge, 2024.

[40] Juan Sandino, Peter A. Caccetta, Conrad Sanderson, Frederic Maire, and Felipe Gonzalez. Reducing object detection uncertainty from rgb and thermal data for uav outdoor surveillance, 2023.

[41] Mor Sinay, Noa Agmon, Oleg Maksimov, Aviad Fux, and Sarit Kraus. Uncertainty with uav search of multiple goal-oriented targets, 2022.

[42] Zhichao Han, Ruibin Zhang, Neng Pan, Chao Xu, and Fei Gao. Fast-tracker: A robust aerial system for tracking agile target in cluttered environments, 2020.

[43] Emmanouil Fountoulakis, Georgios S. Paschos, and Nikolaos Pappas. Uav trajectory optimization for time constrained applications, 2020.

[44] Phuoc Nguyen Thuan, Jorge Peña Queralta, and Tomi Westerlund. Simulation analysis of exploration strategies and uav planning for search and rescue, 2023.

[45] Fei Dong, Keyou You, and Jiaqi Zhang. Flight control for uav loitering over a ground target with unknown maneuver, 2019.

[46] Lima Agnel Tony, Shuvrangshu Jana, Varun V P, Vidyadhara B V au2, Mohitvishnu S Gadde, Abhishek Kashyap, Rahul Ravichandran, and Debasish Ghose. Collaborative tracking and capture of aerial object using uavs, 2020.

[47] Alan Roder, Kim-Kwang Raymon Choo, and Nhien-An Le-Khac. Unmanned aerial vehicle forensic investigation process: Dji phantom 3 drone as a case study, 2018.

[48] Ragib Amin Nihal, Benjamin Yen, Katsutoshi Itoyama, and Kazuhiro Nakadai. Uav-enhanced combination to application: Comprehensive analysis and benchmarking of a human detection dataset for disaster scenarios, 2024.

[49] Nan Jiang, Kuiran Wang, Xiaoke Peng, Xuehui Yu, Qiang Wang, Junliang Xing, Guorong Li, Jian Zhao, Guodong Guo, and Zhenjun Han. Anti-uav: A large multi-modal benchmark for uav tracking. *arXiv preprint arXiv:2101.08466*, 2021.

[50] Chanyoung Ju and Hyoung Il Son. Multiple uav systems for agricultural applications: Control, implementation, and evaluation. *Electronics*, 7(9):162, 2018.

[51] Jinho Kim, S. Andrew Gadsden, and Stephen A. Wilkerson. A comprehensive survey of control strategies for autonomous quadrotors, 2020.

[52] Andreas Anastasiou, Angelos Zacharia, Savvas Papaioannou, Panayiotis Kolios, Christos G. Panayiotou, and Marios M. Polycarpou. Automated real-time inspection in indoor and outdoor 3d environments with cooperative aerial robots, 2024.

[53] Xinhang Xu, Muqing Cao, Shenghai Yuan, Thien Hoang Nguyen, Thien-Minh Nguyen, and Lihua Xie. A cost-effective cooperative exploration and inspection strategy for heterogeneous aerial system, 2024.

[54] Michaela Cihlářová, Václav Pritzl, and Martin Saska. Cooperative indoor exploration leveraging a mixed-size uav team with heterogeneous sensors, 2024.

[55] Kaya Kuru, John Michael Pinder, Benjamin Jon Watkinson, Darren Ansell, Keith Vinning, Lee Moore, Chris Gilbert, Aadithya Sujit, and David Jones. Toward collision-free trajectory for autonomous and pilot-controlled unmanned aerial vehicles, 2023.

[56] Anish Bhattacharya. Toward increased airspace safety: Quadrotor guidance for targeting aerial objects, 2021.

[57] Amit Raj, Kapil Ahuja, and Yann Busnel. Ai algorithm for predicting and optimizing trajectory of uav swarm, 2024.

[58] Mohamed-Amine Lahmeri, Mustafa A. Kishk, and Mohamed-Slim Alouini. Artificial intelligence for uav-enabled wireless networks: A survey, 2021.

[59] Daniel Bonilla Licea, Viktor Walter, Mounir Ghogho, and Martin Saska. Optical communication-based identification for multi-uav systems: theory and practice, 2023.

[60] Deyi Ji, Siqi Gao, Lanyun Zhu, Qi Zhu, Yiru Zhao, Peng Xu, Hongtao Lu, Feng Zhao, and Jieping Ye. View-centric multi-object tracking with homographic matching in moving uav, 2024.

[61] Yuanwei Wu, Yao Sui, and Guanghui Wang. Vision-based real-time aerial object localization and tracking for uav sensing system, 2017.

[62] Eung-Joo Lee, Damon M. Conover, Shuvra S. Bhattacharyyaa, Heesung Kwon, Jason Hill, and Kenneth Evensen. Validation of object detection in uav-based images using synthetic data, 2022.

[63] Chenjie Zhao, Ryan Wen Liu, Jingxiang Qu, and Ruobin Gao. Deep learning-based object detection in maritime unmanned aerial vehicle imagery: Review and experimental comparisons, 2023.

[64] Subrahmanyam Vaddi, Chandan Kumar, and Ali Jannesari. Efficient object detection model for real-time uav applications, 2019.

[65] Adnan Munir, Abdul Jabbar Siddiqui, and Saeed Anwar. Investigation of uav detection in images with complex backgrounds and rainy artifacts, 2023.

[66] Simon Bultmann, Jan Quenzel, and Sven Behnke. Real-time multi-modal semantic fusion on unmanned aerial vehicles, 2021.

[67] Sara Hatami Gazani, Fardad Dadboud, Miodrag Bolic, Iraj Mantegh, and Homayoun Najjaran. Object semantics give us the depth we need: Multi-task approach to aerial depth completion, 2023.

[68] Amirmasoud Ghasemi Toudeshki, Faraz Shamshirdar, and Richard Vaughan. Uav visual teach and repeat using only semantic object features, 2018.

[69] Anli Lim, Bharath Ramesh, Yue Yang, Cheng Xiang, Zhi Gao, and Feng Lin. Real-time optical flow-based video stabilization for unmanned aerial vehicles, 2017.

[70] Giuseppe Silano and Luigi Iannelli. Mat-fly: An educational platform for simulating unmanned aerial vehicles aimed to detect and track moving objects, 2021.

[71] Diego Dantas, Carnot Braun, Kaio Forte, Flavio Brito, Andrey Silva, Silvia Lins, Neiva Linder, and Aldebaro Klautau. Testbed for connected artificial intelligence using unmanned aerial vehicles and convolutional pose machines, 2020.

[72] Xuesu Xiao, Jan Dufek, and Robin R. Murphy. Autonomous visual assistance for robot operations using a tethered uav, 2019.

[73] Yaniv Altshuler, Alex Pentland, Shlomo Bekhor, Yoram Shiftan, and Alfred Bruckstein. Optimal dynamic coverage infrastructure for large-scale fleets of reconnaissance uavs, 2016.

[74] Jasper Brown, Cameron Clark, Sabrina Lomax, Khalid Rafique, and Salah Sukkarieh. Manipulating uav imagery for satellite model training, calibration and testing, 2022.

[75] Haemin Lee, Soyi Jung, and Joongheon Kim. Distributed and autonomous aerial data collection in smart city surveillance applications, 2021.

[76] Wahab Khawaja, Martins Ezuma, Vasilii Semkin, Fatih Erden, Ozgur Ozdemir, and Ismail Guvenc. A survey on detection, tracking, and classification of aerial threats using radars and communications systems, 2022.

[77] Raed Abu Zitar, Mohammad Al-Betar, Mohamad Ryalat, and Sofian Kassaymeh. A review of uav visual detection and tracking methods, 2023.

[78] Marco Esposito, Toni Mancini, and Enrico Tronci. Optimizing fault-tolerant quality-guaranteed sensor deployments for uav localization in critical areas via computational geometry, 2023.

[79] Yousef Emami, Kai Li, Luis Almeida, Sai Zou, and Wei Ni. On the use of immersive digital technologies for designing and operating uavs, 2025.

[80] Won Joon Yun, Soohyun Park, Joongheon Kim, MyungJae Shin, Soyi Jung, David A. Mohaisen, and Jae-Hyun Kim. Cooperative multi-agent deep reinforcement learning for reliable surveillance via autonomous multi-uav control, 2022.

[81] Changhong Fu, Xiang Lei, Haobo Zuo, Liangliang Yao, Guangze Zheng, and Jia Pan. Progressive representation learning for real-time uav tracking, 2024.

[82] Shriyanti Kulkarni, Vedashree Chaphekar, Md Moin Uddin Chowdhury, Fatih Erden, and Ismail Guvenc. Uav aided search and rescue operation using reinforcement learning, 2020.

[83] Manuel Luis C. Delos Santos, Jerum B. Dasalla, Jomar C. Feliciano, and Dustin Red B. Cabatay. Icarus: An android-based unmanned aerial vehicle (uav) search and rescue eye in the sky, 2023.

[84] Matheus G. Mateus, Ricardo B. Grando, and Paulo L. J. Drews-Jr. Active perception applied to unmanned aerial vehicles through deep reinforcement learning, 2022.

[85] Haobin Chen, Junyu Tao, Bize Zhou, and Xiaoyan Liu. Research on an autonomous uav search and rescue system based on the improved, 2024.

[86] Mayank Mittal, Rohit Mohan, Wolfram Burgard, and Abhinav Valada. Vision-based autonomous uav navigation and landing for urban search and rescue, 2019.

[87] Ilario Antonio Azzollini, Nicola Mimmo, Lorenzo Gentilini, and Lorenzo Marconi. Uav-based search and rescue in avalanches using arva: An extremum seeking approach, 2021.

[88] Vatsal Aggarwal, Arjun Ramesh Kaushik, Charanjit Jutla, and Nalini Ratha. Enhancing privacy and security of autonomous uav navigation, 2024.

[89] Azza Allouch, Anis Koubaa, Mohamed Khalgui, and Tarek Abbes. Qualitative and quantitative risk analysis and safety assessment of unmanned aerial vehicles missions over the internet, 2019.