Review On Drone Applications Using Computer Vision For Environmental Observation

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Abstract - The integration of drones with computer vision has transformed methods for environmental observation, enabling new levels of detail, accuracy, and automation. This paper presents a comprehensive review of recent research on the application of drones equipped with computer vision for monitoring diverse environmental settings, including aquatic ecosystems, agricultural fields, forests, and urban areas. Recent studies demonstrate drones' effectiveness in tracking fish behaviour, assessing water quality, monitoring crop health, analysing soil, and observing wildlife and urban environments for air quality and traffic. Key computer vision techniques, such as image classification, object detection, 3D mapping, and behavioural tracking, enable real-time data analysis; however, challenges like battery constraints, image quality issues, and ethical concerns persist. Emerging trends, including edge AI and improved hardware, promise to enhance drone resilience and autonomy, with broad implications for conservation, agriculture, and urban management.

Index Terms - Drones, Computer Vision, Environmental Monitoring, Aquatic and Agricultural Surveillance, Edge AI and Autonomous Systems.

I. Introduction

The integration of computer vision with drone technology has revolutionized the field of environmental observation, offering unprecedented accuracy and automation in monitoring various environments. Recent advancements in deep learning algorithms, hardware capabilities, and access to large-scale datasets have significantly enhanced object detection and tracking systems, pivotal components for analysing drone-captured data. Object detection, the task of identifying and localizing objects within images, forms the foundation for more complex applications like activity recognition, scene comprehension, and real-time surveillance.

Drones, equipped with cameras, are increasingly used across diverse fields such as surveillance, agriculture, disaster management, and marine monitoring. In particular, drones in precision agriculture have gained prominence, offering farmers tools for crop monitoring, soil analysis, and efficient pesticide use, thus improving productivity and sustainability. Similarly, drones have shown immense potential in monitoring fish behaviour, tracking wildlife, and assessing environmental health in aquatic and forest ecosystems. Their utility extends to urban areas, where they assist in monitoring air quality, traffic patterns, and other key environmental indicators.

II. Literature survey

Recent studies have identified the need to adapt traditional object detection algorithms to handle these challenges. Some important initiatives in addressing these challenges include:

1.The VisDrone 2018 Benchmark: A large-scale dataset with over 25 million annotated object instances, designed to facilitate the development of new object detection and tracking algorithms for drones.

2.Advancements in Object Detection: Improvements in deep learning models and computer vision techniques, such as the use of convolutional neural networks (CNNs) and generative models, to enhance the accu racy and efficiency of object detection in drone imagery.

3.Benchmark Datasets: Datasets like Caltech, KITTI, ImageNet, and MS COCO, which have been instrumental in advancing object detection research, are now being extended to include drone-specific scenarios.

The development of large, annotated datasets for drone applications remains a critical factor in advancing this field. These datasets not only address the data scarcity issue but also offer valuable resources for the evaluation and comparison of new algorithms.

In this paper, we review the latest developments in drone-based computer vision applications, focusing on the advancements in object detection, tracking, and environmental monitoring. We explore the different challenges encountered in these applications and examine the future potential of drones in providing more efficient and accurate environmental insights. The integration of edge AI, the improvement of drone hardware, and the development of comprehensive datasets will continue to drive innovation in this field, expanding the capabilities of drones for environmental observation.

Related Work: Research on UAV-based target detection and tracking has significantly progressed, especially in civil applications, and is now being adapted for crucial tasks in emergency and environmental monitoring. Studies in this field address both application-focused and methodological advances, with the following highlights:

SAR (Search and Rescue) and Disaster Management: UAVs are widely used in SAR operations post-natural disasters like earthquakes and offshore accidents. SAR efforts in wildfire detection, for instance, have seen a range of methods using color, infrared images, and smoke sensors to improve detection accuracy. Algorithms focusing on resource allocation, path optimization, and mobility planning enhance UAV performance in vast areas.

Deep Learning and Computer Vision: Extensive reviews, such as by Carrio et al. (2017), outline deep learning methods that optimize UAV operations in scene classification, object recognition, and situational awareness. Advanced CNN-based architectures like MobileNetV2 leverage transfer learning to reduce computational costs while retaining high accuracy, essential for UAVs operating in resource-constrained environments.

Path and Task Planning: Effective mobility planning remains critical for UAV missions in large-scale disaster zones. Techniques range from layered algorithms for multiple UAV coordination to Markov decision processes (Dec-POMDP) for handling uncertainties, especially in multi-robot SAR missions. Task allocation studies, such as those by Boursianis et al. (2020), have examined coordination with unmanned ground vehicles (UGVs) to enhance area coverage.

Agriculture and Smart Farming: The agricultural sector benefits from UAVs equipped with IoT and AI-enabled sensors, which assist in crop monitoring, pesticide application, and soil assessment. Del Cerro et al. (2021) highlight UAV use in smart farming, where sensors support precision agriculture. Similarly, Chandra et al. (2020) discuss plant phenotyping through deep learning in agricultural UAVs.

Civil Infrastructure and Market Growth: Drones are increasingly used in civil infrastructure for inspection and maintenance, with the potential to reach a market value of $45 billion. Studies on civil applications, such as by Shakhatreh et al. (2019), address challenges like charging, network security, collision avoidance, and swarming, which are critical for future expansion.

Despite these advances, few studies offer a unified framework that addresses both object detection and path planning. This research aims to bridge that gap by presenting a comprehensive approach integrating detection algorithms with optimal path planning, crucial for enhancing UAV performance in various dynamic and real-world settings.

Identified Research Gap: Despite significant advancements, deep learning methods, drone technologies, and their integration still face various unresolved challenges.

1.Deep learning methods for drones face unresolved challenges, such as understanding why certain architectures perform better than others and the absence of geometric considerations in objective functions. Efficient unsupervised learning methods are essential, as labelling large datasets is costly.

2.Researchers currently rely on either deep learning or traditional image processing for object detection in drones. However, drones' constraints on weight, size, and power make onboard deep learning processing difficult, especially when transmitting large image data with limited bandwidth.

3.Real-time UAV applications bring security and privacy risks due to internet use. There is a clear need for tailored security measures specific to UAV operations.

Applications of Drones in Environmental Observation:

Drones, equipped with computer vision and specialized sensors, are increasingly applied in aquatic environments to study fish behavior and monitor water quality. By capturing real-time data through high-resolution imaging, drones assist in understanding species interactions, tracking fish migration, and identifying environmental stressors. This non-invasive approach offers significant advantages for ecosystem monitoring and sustainable management practices in aquaculture and marine conservation.

Precision agriculture benefits extensively from drones that provide detailed imagery and data on crop health and soil composition. Utilizing multispectral and thermal cameras, drones can detect variations in crop growth, water stress, and pest activity, allowing for targeted intervention. This technology contributes to efficient resource allocation, supports higher yields, and promotes sustainable agriculture by minimizing chemical inputs and water use.

Drones are valuable tools for forest and wildlife monitoring, offering insights into deforestation rates, habitat changes, and wildlife distribution without disrupting natural ecosystems. By mapping vegetation cover, tracking forest regrowth, and monitoring wildlife, drones facilitate biodiversity conservation and contribute to efforts aimed at protecting endangered species. The data gathered is instrumental in making informed decisions regarding forest and wildlife management.

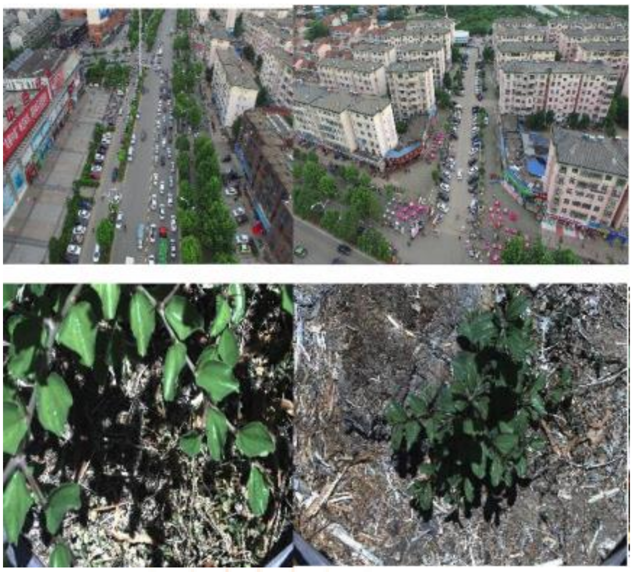

Fig 1: Some example of UAV images.

In urban settings, drones equipped with environmental sensors and computer vision systems are used to monitor air quality and environmental health. They collect real-time data on pollutants and particulate matter, providing critical information for mitigating urban air pollution. Drones also assist in traffic and infrastructure analysis, aiding in urban planning and environmental protection efforts that support public health and sustainable city development.

Fig 2 : Illustration of four typical types of CV tasks (from left): image classification (i.e. is there a fish in the image, or what type (class) of fish is in the image?), object detection/localization, semantic segmentation and instance segmentation

Object Detection Developement:

In my recent study, I explored the evolution of object detection algorithms, which can be categorized into two phases: traditional object detection methods and deep-learning-based approaches. Deep-learning-based object detection has progressed into two main types: one-stage and two-stage algorithms. Figure 3 illustrates this development, spanning from 2001 to 2023. Traditional object detection methods primarily relied on sliding window techniques and manual feature extraction, typically involving three steps: region proposal, feature extraction, and classification regression. The region proposal step aims to identify areas of interest where objects are likely located. In feature extraction, manual techniques are applied to transform candidate image regions into feature vectors. Finally, a classifier is used to categorize objects based on the extracted features. However, these traditional methods tend to have limitations, such as high computational complexity, limited feature representation capabilities, and challenges in optimization. Notable examples include the Viola-Jones detector and the HOG-based pedestrian detector.

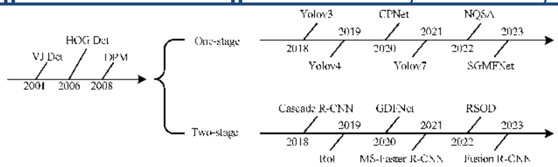

Fig 3: The development of object detection from 2001-2023

Behavioral Analysis and Tracking:

Behavioral analysis and tracking involve observing and following the movements of objects or subjects, such as animals in conservation areas, human crowds, or traffic flow in urban areas. Drones equipped with tracking algorithms, such as optical flow or deep-learning-based motion detection, can monitor patterns and behaviors over time. For instance, tracking animal movements provides insights into migration routes or habitat usage, while monitoring human or vehicle flow helps city planners manage congestion. This capability is especially valuable for real-time analysis, as it supports timely responses to environmental or social dynamics.

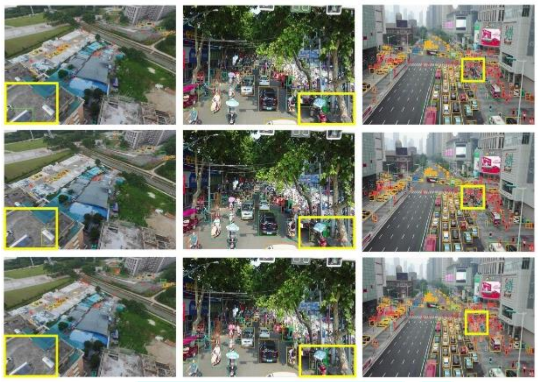

Fig 4: Continous Behaviour Change Analysis

AI and edge computing are transforming drone-based observation by enabling real-time data processing directly on the drone, reducing the need for data transmission to remote servers. AI algorithms, such as deep learning, allow drones to perform complex tasks like object detection, environmental monitoring, and behavioral analysis autonomously. Edge computing minimizes latency and bandwidth issues, allowing drones to make decisions quickly without relying on cloud connectivity. This advancement is particularly useful in applications such as disaster response, agriculture, and wildlife monitoring, where immediate data analysis is essential for decision-making in dynamic environments.

Autonomous monitoring refers to the ability of drones to perform continuous surveillance and data collection without human intervention. By integrating AI, machine learning, and advanced sensors, drones can analyze their surroundings, detect changes, and make decisions in real-time. This capability is valuable in applications like environmental monitoring, wildlife conservation, and disaster management, where drones can autonomously track patterns, detect anomalies, and respond to environmental changes. Autonomous monitoring reduces human labor, enhances operational efficiency, and allows for the continuous, real-time assessment of large or hard-to-reach areas, improving decision-making and resource allocation.

The case study of edinburgh grit bins:

In this case study, the proposed algorithm was tested using real-world data to evaluate its performance in disseminating information through a wireless sensor network (WSN) with a drone. The scenario focused on a city's grit bins, each equipped with wireless sensors for various smart city applications. The data used for the study was based on the locations of 1,000 grit bins in Edinburgh, Scotland, retrieved from the City of Edinburgh Council. After excluding bins in remote areas, the remaining 880 bins were used as the nodes in the network.

The network's layout was based on the city's road topology, where the bins are more concentrated in the city center and sparse in the outskirts. The drone’s mission was to periodically collect data from these sensors by flying along pre-planned routes, such as vertical lines, squares, rhombuses, and circles. The connectivity radius for the sensors was carefully chosen to ensure effective communication, avoiding disconnected networks or overly dense ones.

The results demonstrated how the drone's route, designed to cover the sensor nodes in the network, varied based on the shape of the path. The case study highlighted the importance of real-world datasets for evaluating network connectivity and performance in urban environments.

III. CONCLUSIONS

In conclusion, the integration of drones with advanced technologies like AI, computer vision, and edge computing holds significant promise for a wide range of applications, including environmental observation, disaster response, and resource management. While the development of object detection and autonomous monitoring systems has made substantial progress, challenges remain in improving the efficiency and accuracy of these systems, particularly in terms of processing power, data transmission, and real-time analysis. However, continued advancements in AI algorithms, hardware innovations, and edge computing are paving the way for more robust and efficient drone systems. As these technologies evolve, drones will increasingly play a critical role in autonomous monitoring, offering valuable insights and real-time data for informed decision-making across diverse industries.

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