



DRONE-ENABLED WILDLIFE MONITORING SYSTEM: REVOLUTIONIZING CONSERVATION EFFORTS

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ABSTRACT:

Drone-enabled wildlife monitoring systems have emerged as a revolutionary approach to studying and conserving wildlife populations and their habitats. This article provides a concise overview of the concept and significance of drone-enabled wildlife monitoring. Drone technology offers unique advantages in wildlife monitoring, including aerial perspectives, maneuverability, and non-intrusive data collection. Equipped with advanced sensors and cameras, drones can capture high-resolution imagery, thermal data, and even acoustic signals, providing valuable insights into wildlife behaviors, population dynamics, and habitat conditions. By employing drones, researchers and conservationists can efficiently cover large areas, access remote or challenging terrains, and monitor elusive or endangered species. The collected data can be processed using state-of-the-art algorithms for species identification, habitat mapping, and population analysis. This article highlights the key components, challenges, and future prospects of drone-enabled wildlife monitoring systems. It underscores the importance of responsible implementation, collaborative efforts, and technological advancements in harnessing the full potential of drones for wildlife conservation and management.

Keywords: Drone enabled Wildlife monitoring system, Edge computing, LiDAR scanners

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INTRODUCTION:

In recent years, technological advancements have been making significant contributions to various fields, and wildlife conservation is no exception. The emergence of drone technology has revolutionized the way we monitor and protect wildlife populations and

their habitats. With their aerial capabilities and advanced imaging systems, drones have become an invaluable tool for researchers, conservationists, and wildlife managers worldwide. This article explores the use of drone-enabled wildlife monitoring systems and the remarkable impact they have had on



conservation efforts. The traditional methods of monitoring wildlife, such as ground surveys and manned aerial surveys, are often time-consuming, costly, and limited in their scope. They can also disturb natural ecosystems and stress animals, leading to biased data collection. However, drone technology has opened up new possibilities for monitoring wildlife in a more efficient, accurate, and non-intrusive manner.¹

One of the key advantages of drones in wildlife monitoring is their ability to provide an aerial perspective. Equipped with high-resolution cameras and thermal sensors, drones can capture detailed images and videos of vast areas, including remote and inaccessible locations.² This aerial view offers crucial insights into animal behavior, habitat conditions, and population dynamics, allowing researchers to make informed decisions and devise effective conservation strategies. Drones also enable real-time monitoring, which is particularly valuable for tracking elusive or endangered species. By deploying drones equipped with GPS and telemetry systems, researchers can monitor the movements and behaviors of individual animals in real-time. This data helps in understanding migration patterns, habitat preferences, and identifying potential threats to the species. Such information is instrumental in designing protected areas, implementing conservation measures, and mitigating human-wildlife conflicts. Another significant application of drone technology in wildlife monitoring is the use of thermal imaging. Thermal cameras mounted on drones can detect heat signatures emitted by animals, making them highly effective in locating and monitoring nocturnal species or animals hiding in dense vegetation.³ This technology has been particularly useful in studying endangered species like tigers, elephants, and rhinoceroses, enabling researchers to estimate population sizes, identify poaching activities, and assess overall health conditions.

Furthermore, drones equipped with advanced image processing and machine learning algorithms have the potential to automate wildlife monitoring tasks. By analyzing aerial

imagery and employing object recognition techniques, drones can detect and classify different species, count individuals, and map their distribution. This automation significantly reduces the time and effort required for data collection and analysis, allowing researchers to focus more on conservation actions and policy-making. Drone-enabled wildlife monitoring systems are also aiding in disaster response and recovery efforts. In the wake of natural disasters such as wildfires, floods, or earthquakes, drones can quickly assess the impact on wildlife habitats, identify injured animals, and locate survivors. This information helps prioritize rescue and rehabilitation efforts, minimizing the ecological impact and promoting swift recovery of affected ecosystems.⁴

While the benefits of drone technology in wildlife monitoring are undeniable, challenges still exist. Regulatory frameworks for drone operations, concerns over privacy, and limitations of battery life and flight range are some of the factors that need to be addressed. Collaboration between researchers, conservation organizations, and regulatory authorities is crucial to ensure responsible and ethical use of drones in wildlife monitoring, minimizing any potential negative impacts. Drone-enabled wildlife monitoring systems have emerged as a game-changer in conservation efforts. With their aerial capabilities, high-resolution imaging, and real-time monitoring capabilities, drones provide valuable insights into animal behavior, habitat conditions, and population dynamics. They enhance data collection efficiency, reduce costs, and offer a non-intrusive approach to studying and protecting wildlife. As technology continues to evolve, drones hold immense potential for advancing our understanding of ecosystems, aiding in conservation planning, and safeguarding the delicate balance of our natural world.^{5,6}

DRONE-ENABLED WILDLIFE MONITORING SYSTEM: UNDERSTANDING THE SETUP

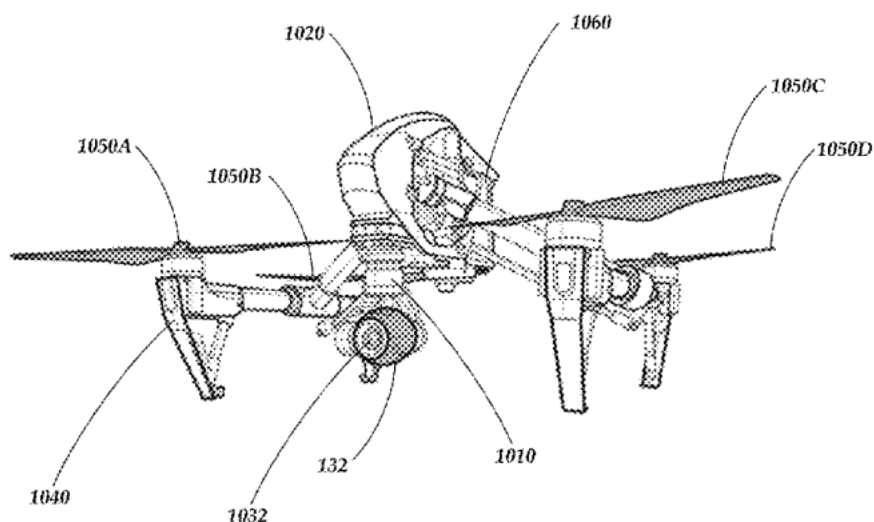
A drone-enabled wildlife monitoring system consists of several key components that work together to collect data, analyze information,



and support conservation efforts. The drone itself is the primary component of the system. It can be a quadcopter, fixed-wing, or hybrid drone, depending on the specific requirements of the monitoring task. The drone platform should be capable of stable flight, carrying payloads (sensors and cameras), and executing predefined flight paths autonomously or under human control. Drones are equipped with various sensors and cameras to capture data about the environment and wildlife.⁷ High-resolution cameras, including RGB, multispectral, or thermal cameras, provide visual and thermal imagery of the monitored area. Other sensors, such as LiDAR (Light Detection and Ranging) or hyperspectral sensors, may be used for collecting additional data about vegetation density, elevation, or specific spectral signatures. To ensure accurate positioning and navigation, drones are equipped with GPS (Global Positioning System) receivers and navigation systems. These systems provide real-time location information, altitude, and heading data, allowing precise flight planning, navigation, and tracking of the drone during monitoring missions. Drones are equipped with onboard storage capabilities to temporarily store collected data during flights. However, for real-time monitoring and immediate analysis, drones often incorporate wireless communication systems (such as Wi-Fi or cellular networks) to transmit data to ground stations or cloud-based storage systems.⁸ This enables researchers and conservationists to access and analyze the data promptly. The ground control station serves as the command center for operating and monitoring the drone. It typically consists of a computer or a mobile device with specialized software that allows the operator to plan flight paths, monitor live video feeds from the drone's cameras, adjust settings, and

control the drone's movements manually or through autonomous flight modes. Once the data is collected, it needs to be processed and analyzed to extract meaningful information. This involves using specialized software for image and data processing, including georeferencing, image stitching, object detection, and classification algorithms. Advanced techniques like machine learning and computer vision are often employed to automate data analysis tasks and facilitate species identification, population estimation, and habitat mapping. To maximize the usefulness of the collected data, it is essential to integrate the drone monitoring system with existing conservation databases and platforms.⁹ This allows for seamless data sharing and collaboration among researchers, conservation organizations, and policymakers. Integration with Geographic Information Systems (GIS) enables spatial analysis and visualization of the collected data, facilitating informed decision-making. Operating drones for wildlife monitoring requires compliance with local regulations and guidelines. It is crucial to adhere to flight restrictions, privacy laws, and ethical guidelines to ensure the well-being of wildlife and minimize any negative impact on the environment. Collaboration with regulatory authorities, obtaining necessary permits, and following ethical protocols is essential for responsible drone-enabled wildlife monitoring. By combining these key components, drone-enabled wildlife monitoring systems offer a comprehensive and efficient approach to collecting accurate and timely data about wildlife populations, behavior, and habitat conditions.^{10,11} The integration of technology with conservation efforts provides valuable insights for conservation planning, policy-making, and the protection of biodiversity.





*Fig. 1 a representation drone-enabled wildlife monitoring
(Ref: US 10,716,292 B1; Dt. Mar. 14, 2018)*

DRONE-ENABLED WILDLIFE MONITORING: NEW DEVELOPMENTS

The field of drone-enabled wildlife monitoring is rapidly evolving, and there have been several recent technological advancements that have further enhanced the capabilities and effectiveness of these systems. The quality and capabilities of sensors and cameras mounted on drones have significantly improved. High-resolution cameras with advanced image stabilization and zoom capabilities allow for detailed aerial imagery, enabling researchers to capture fine-grained data about wildlife behavior and habitat conditions. Furthermore, the integration of multispectral and hyperspectral sensors provides valuable insights into vegetation health, species identification, and ecosystem dynamics. Artificial intelligence (AI) and machine learning (ML) techniques have made substantial contributions to drone-enabled wildlife monitoring. These technologies enable automated data analysis, including object detection, species recognition, and population estimation. By training algorithms on large datasets, drones can autonomously detect and classify animals, helping researchers analyze vast amounts of data efficiently and accurately.⁴ Advancements in onboard computing power and data processing algorithms have enabled real-time

data processing and analytics capabilities in drones. This means that data collected by drones can be processed onboard or quickly transmitted to ground stations for immediate analysis. Real-time analytics provide instant feedback and insights, allowing researchers and conservationists to make timely decisions and take appropriate actions based on the collected data.

Edge computing refers to processing data locally on the drone or at the edge of the network, rather than sending it to a centralized server or cloud. This approach reduces latency, increases data privacy, and allows for faster decision-making. Edge computing enables drones to perform computationally intensive tasks, such as image processing and object detection, in real-time without relying heavily on external computing resources. Recent advancements in drone software and navigation systems have improved the automation of flight planning and execution. Drones can now autonomously navigate complex terrains, avoid obstacles, and follow predefined flight paths accurately. This automation reduces the workload on operators and ensures consistent and reliable data collection, even in challenging environments.

Battery technology advancements have led to increased flight times and extended ranges for drones. Longer flight durations allow for more

extensive coverage and prolonged monitoring sessions without the need for frequent battery changes.⁵ This is particularly beneficial when monitoring large wildlife habitats or tracking animals with extensive ranges, such as migratory species. Drone swarms, where multiple drones operate collaboratively, have gained attention in wildlife monitoring. Swarms can cover larger areas simultaneously, coordinate their movements to optimize data collection, and work together to achieve common goals. Swarms enable researchers to monitor wildlife populations more efficiently, improve data accuracy through redundant measurements, and enhance situational awareness.

The visualization and integration of drone-collected data have become more sophisticated. Geographic Information Systems (GIS) software and platforms offer advanced mapping, spatial analysis, and data visualization capabilities. Integration with conservation databases, wildlife monitoring platforms, and existing ecological models allows for a comprehensive understanding of the collected data and its implications for conservation decision-making. These recent technological advancements in drone-enabled wildlife monitoring systems have transformed the way researchers study and protect wildlife. The integration of advanced sensors, AI/ML algorithms, real-time data processing, and improved flight capabilities has enhanced data collection efficiency, analysis accuracy, and decision-making for conservation efforts. Continued innovation and collaboration in this field hold tremendous potential for further advancing wildlife monitoring and conservation practices.

DRONE-ENABLED WILDLIFE MONITORING SYSTEM: VARIOUS WAYS OF EXECUTION

The implementation of a drone-enabled wildlife monitoring system involves several key methods and steps to ensure successful deployment and effective data collection. The first step is to define the objectives of the wildlife monitoring project. This includes identifying the target species, studying their behavior and habitat requirements, and determining the specific data needs. Clear

objectives help in selecting appropriate drone platforms, sensors, and flight parameters. Depending on the monitoring requirements, the choice of drone platform will vary.⁶ Factors such as flight endurance, payload capacity, stability, and maneuverability need to be considered. Different drone types, including quadcopters, fixed-wing drones, or hybrid models, may be suitable based on the study area, desired flight duration, and payload requirements. Selecting the right sensors and cameras is crucial for collecting accurate and relevant data. High-resolution cameras, thermal imaging sensors, multispectral or hyperspectral sensors, or LiDAR scanners may be chosen based on the specific objectives of the monitoring project. The sensors should be compatible with the drone platform and capable of capturing the required data.

Flight planning involves defining the flight area, altitude, flight path, and specific waypoints for data collection. Various software and applications are available that assist in creating flight plans and autonomous missions. These plans ensure efficient coverage of the study area and systematic data collection. During flight execution, the drone should be closely monitored to ensure smooth operation and adherence to the planned flight path. Drones capture aerial imagery, video footage, or other sensor data during the flight missions. The collected data needs to be stored securely on the drone's onboard storage or transmitted wirelessly to ground stations for immediate processing. Proper data management protocols, including backups and metadata documentation, should be followed to ensure the integrity and accessibility of the collected data. Once the data is collected, it needs to be processed and analyzed to extract meaningful information. This involves utilizing specialized software and algorithms for tasks such as image stitching, object detection, species classification, or habitat mapping. Advanced techniques like machine learning and computer vision can automate data analysis, facilitating efficient and accurate interpretation of the collected data.

Drone-enabled wildlife monitoring systems often involve collaboration among multiple

stakeholders, including researchers, conservation organizations, and regulatory authorities. Data sharing, integration with existing conservation databases or platforms, and coordination with relevant agencies help ensure a comprehensive and collaborative approach to wildlife monitoring and conservation. It is essential to comply with local regulations and obtain necessary permits for operating drones in wildlife monitoring projects.⁷ Additionally, ethical considerations, such as minimizing disturbance to wildlife and maintaining data privacy, should be prioritized. Collaboration with regulatory authorities and adherence to ethical guidelines contribute to responsible and sustainable implementation of drone-enabled wildlife monitoring systems. By following these methods of implementation, researchers and conservationists can effectively deploy drone technology for wildlife monitoring, gather accurate data, and make informed decisions to protect and conserve wildlife populations and their habitats.

DRONE-ENABLED WILDLIFE MONITORING SYSTEM: UNDERSTANDING THE HARDSHIPS

Implementing a drone-enabled wildlife monitoring system comes with its own set of challenges. One of the significant challenges is navigating the complex and evolving regulations related to drone operations. Different countries and regions have varying restrictions on drone flights, including altitude limits, no-fly zones, and permits required for specific activities such as wildlife monitoring. Obtaining the necessary permits and ensuring compliance with regulations can be time-consuming and may limit the scope of operations. Drones have certain technical limitations that can pose challenges to wildlife monitoring. Limited flight endurance and payload capacity restrict the time and equipment that can be deployed during a single flight. The need to balance battery life and data collection can impact the coverage and duration of monitoring missions. Additionally, adverse weather conditions, such as strong winds or heavy rain, can restrict drone operations. The safety of wildlife and

the avoidance of disturbance are crucial considerations. Drones, especially when operated at low altitudes, can potentially disrupt wildlife behavior, causing stress or altering natural activities. It is essential to develop guidelines and protocols to minimize disturbance and ensure the welfare of the animals being monitored.

The sheer volume of data collected by drones can be overwhelming and present challenges for storage, organization, and analysis. Effective data management systems and protocols are needed to handle large datasets and ensure data integrity. Additionally, analyzing the collected data requires specialized software, algorithms, and expertise in remote sensing, image processing, and species identification, which can be resource-intensive. Operating drones for wildlife monitoring requires skilled personnel who are trained in drone piloting, flight planning, sensor operation, and data analysis.⁸ Training and maintaining a qualified team proficient in drone technology, software applications, and data processing techniques can be a challenge. Ongoing training and staying up-to-date with the latest advancements are necessary to maximize the effectiveness of the system.

The initial investment in acquiring drones, sensors, cameras, and related equipment can be substantial. Additionally, there are ongoing costs associated with maintenance, software licenses, data storage, and personnel. Limited financial resources can present challenges in establishing and sustaining a robust drone-enabled wildlife monitoring system. Drones can raise concerns among the public regarding privacy, noise pollution, and their impact on wildlife and the environment. It is essential to address these concerns through public outreach, education, and transparency about the purpose, benefits, and ethical considerations of drone-enabled wildlife monitoring. Building public trust and acceptance is crucial for the long-term success and support of such initiatives.

Addressing these challenges requires collaboration among researchers, conservation organizations, regulatory bodies, and local communities. By actively addressing

these challenges, the potential of drone-enabled wildlife monitoring systems can be harnessed to contribute significantly to wildlife conservation and management efforts.

USE OF DRONE-ENABLED WILDLIFE MONITORING SYSTEMS: STORY ACROSS THE GLOBE

Drone-enabled wildlife monitoring systems have been implemented in various countries worldwide, showcasing the global applicability and effectiveness of this technology. The United States has been at the forefront of using drones for wildlife monitoring. For instance, in Alaska, drones have been deployed to monitor polar bear populations and their interactions with oil and gas exploration activities. In California, drones have been used to study and protect endangered species like the California condor, aiding in population monitoring and nest site identification.

Australia has embraced drone technology for wildlife monitoring, given its vast and diverse ecosystems. Drones have been utilized to monitor the Great Barrier Reef, providing aerial surveys to assess coral health, detect invasive species, and monitor marine wildlife populations. In addition, drones have aided in tracking and studying the movements of iconic Australian species, including koalas, kangaroos, and various bird species. In Kenya, drones have been employed in wildlife conservation efforts, particularly in the protection of endangered species like rhinoceroses and elephants. Drones equipped with thermal cameras and GPS tracking systems have been instrumental in anti-poaching operations, enabling rangers to monitor wildlife movements, identify potential threats, and respond swiftly to illegal activities. India has utilized drones to monitor its rich biodiversity and address conservation challenges. In Kaziranga National Park, drones have been used to combat rhinoceros poaching by patrolling restricted areas, collecting real-time data, and supporting anti-poaching efforts. Drones have also aided in monitoring tiger populations and tracking migratory bird patterns in various national parks across the country. In the Amazon

rainforest, drones have played a crucial role in monitoring deforestation and protecting wildlife habitats. They have been utilized to detect and document illegal logging activities, monitor the spread of wildfires, and assess the impact on wildlife populations. Drones have also facilitated research on indigenous wildlife species, including monitoring primates, birds, and river dolphins.

South Africa has employed drones for wildlife monitoring and anti-poaching initiatives. Drones equipped with high-resolution cameras and thermal imaging sensors have been used to monitor rhino populations, detect poaching threats, and track poachers' movements. The data collected by drones has proven invaluable in anti-poaching operations and conservation management strategies. In Costa Rica, drones have been utilized for marine wildlife monitoring, focusing on coastal areas and marine reserves. They have aided in tracking sea turtles, monitoring nesting sites, and studying their migration patterns. Drones have also been deployed to assess the health of coral reefs, monitor coastal erosion, and detect illegal fishing activities. These examples demonstrate the global adoption of drone-enabled wildlife monitoring systems, showcasing their effectiveness in diverse ecosystems and conservation contexts. The use of drones has proven instrumental in gathering accurate data, improving conservation efforts, and protecting endangered species and their habitats.

DRONE-ENABLED WILDLIFE MONITORING SYSTEMS: THE WAY FORWARD

The future prospects of drone-enabled wildlife monitoring systems are promising and hold significant potential for advancing wildlife conservation and research. Advancements in drone technology will lead to improved sensors, cameras, and data collection capabilities. Higher-resolution imaging, improved thermal sensors, and enhanced data processing algorithms will enable more detailed and accurate data collection. This will provide researchers with a deeper understanding of wildlife behavior, population dynamics, habitat health, and ecosystem interactions. The integration of artificial



intelligence (AI) and machine learning (ML) algorithms will revolutionize drone-enabled wildlife monitoring. AI-based image recognition and object detection will automate species identification, enabling real-time analysis and faster data processing. ML algorithms will enhance data analytics, allowing drones to learn and adapt to changing environments, optimizing flight paths and data collection strategies. Future drones are expected to have extended flight ranges and longer endurance, enabling them to cover larger areas and monitor wildlife populations over longer periods. Autonomous operations will become more advanced, allowing drones to navigate complex terrains, detect and avoid obstacles, and adapt their flight patterns in real-time. This will improve the efficiency and coverage of wildlife monitoring efforts.

Drone swarms, consisting of multiple coordinated drones, hold great potential for wildlife monitoring. Swarm technology can enable simultaneous data collection from multiple vantage points, providing comprehensive and redundant data. Swarms can cover larger areas, track multiple species simultaneously, and collaborate to optimize data collection and analysis. This approach will improve monitoring accuracy and provide a more holistic understanding of ecosystems. Drone-enabled wildlife monitoring systems will likely integrate with other emerging technologies, such as satellite imagery, remote sensing, and GPS tracking. Integration with satellite data will enhance the spatial resolution and coverage of monitoring efforts. Remote sensing technologies, such as LiDAR, will provide 3D mapping of habitats and improved vegetation analysis.⁹ GPS tracking will enable real-time monitoring of animal movements, migration patterns, and behavior. The future of drone-enabled wildlife monitoring lies in collaboration and data sharing among researchers, organizations, and governments. Establishing collaborative networks and sharing data across borders will enable a global understanding of wildlife populations and facilitate international conservation efforts. Open data initiatives and standardized protocols for data collection,

management, and sharing will foster collaborative research and enhance the impact of drone-enabled monitoring.

The future of drone-enabled wildlife monitoring also depends on public engagement and education. Increasing public awareness about the benefits and ethical considerations of drone technology will help overcome concerns and gain public support. Education initiatives can empower local communities to actively participate in monitoring efforts, contributing to citizen science and promoting a sense of stewardship towards wildlife and their habitats. Overall, the future prospects of drone-enabled wildlife monitoring systems are exciting. Advancements in technology, data analysis, automation, and collaboration will revolutionize wildlife monitoring, providing valuable insights for conservation efforts and aiding in the sustainable management of ecosystems. Continued innovation and research in this field will unlock new possibilities and contribute to the preservation of biodiversity and the protection of wildlife populations worldwide.

CONCLUSION:

In conclusion, drone-enabled wildlife monitoring systems have emerged as a powerful tool for studying and conserving the world's wildlife. These systems offer numerous advantages, including enhanced data collection capabilities, improved efficiency, and reduced disturbance to wildlife. By leveraging advancements in drone technology, sensors, and data analysis, researchers and conservationists can gather detailed and accurate information about wildlife populations, behaviors, and habitats. The key components of a drone-enabled wildlife monitoring system, such as drones, sensors, cameras, and data management processes, work together to enable effective monitoring and analysis. However, there are challenges to overcome, including regulatory compliance, technical limitations, safety concerns, data management, and public perception. Addressing these challenges requires collaboration, ongoing training, and adherence to ethical guidelines to ensure responsible and sustainable implementation

of drone technology. Looking towards the future, the prospects for drone-enabled wildlife monitoring are promising. Technological advancements will continue to enhance data collection, analysis, and automation, enabling more precise and comprehensive monitoring efforts. Integration with other technologies, such as satellite imagery, remote sensing, and GPS tracking, will further improve the accuracy and scope of wildlife monitoring. Collaborative networks and data sharing initiatives will facilitate global understanding and collaborative conservation efforts. Drone-enabled wildlife monitoring systems have the potential to revolutionize wildlife research, conservation, and management. By providing valuable insights into wildlife populations, habitat health, and ecosystem dynamics, these systems contribute to evidence-based decision-making and the protection of biodiversity. With continued innovation, public engagement, and responsible implementation, drone-enabled wildlife monitoring will play a crucial role in preserving our planet's natural heritage for generations to come.

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