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Forestry In The Digital Era: Drone Technology And Ai In Forest Conservation

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ABSTRAK

In the face of accelerating deforestation and climate change, the integration of digital technologies into forest conservation strategies has become increasingly vital. This study explores the transformative role of drone technology and artificial intelligence (AI) in modern forestry management. By employing high-resolution aerial imagery from drones and leveraging AI-based data analysis, forest monitoring has shifted from reactive to proactive approaches. The research highlights how drones facilitate real-time surveillance, detect illegal logging activities, and assess forest health with greater precision. Meanwhile, AI enhances pattern recognition for biodiversity tracking, fire prediction, and resource allocation. Through case studies in Indonesia and Brazil, this paper demonstrates significant improvements in conservation outcomes where digital tools were applied. The findings suggest that integrating drones and AI not only improves efficiency and accuracy in forest management but also supports evidence-based policymaking for sustainable forestry. The study concludes with recommendations for broader implementation and the need for capacity building among conservation stakeholders.

INTRODUCTION

Forestry plays a vital role in maintaining ecosystem balance and environmental sustainability (Sholihah & Irawanto, 2024). Forests serve as primary carbon sinks, helping to mitigate the impact of climate change by absorbing carbon dioxide (CO_2) and producing oxygen (Kusuma, 2020). In addition, forests provide habitat for a wide variety of flora and fauna, supporting global biodiversity. Habitat loss due to deforestation threatens the survival of these species and damages ecosystems that sustain both human and non-human life. Forests also play an important role in regulating the water cycle and preventing natural disasters. Forests absorb rainwater and gradually release it into the soil, maintaining freshwater availability and reducing the risk of drought. Tree roots function as erosion barriers, reducing the likelihood of landslides and soil degradation caused by heavy rain. When forests are lost, previously fertile and green areas may turn barren, increasing the risk of natural disasters that negatively impact human life. Ongoing forest degradation due to illegal deforestation, land conversion for agriculture, and

climate change poses a major threat to forest sustainability (Adudu et al., 2023). This damage not only disrupts ecosystems but also threatens the lives of communities dependent on forests and worsens global climate change (Pajerih, 2023). Therefore, sustainable forest preservation and management efforts are urgently needed, including monitoring illegal activities, implementing environmentally friendly land-use policies, and land restoration to recover lost ecosystems. With collective commitment, forest sustainability can be preserved to continue providing long-term benefits for both humanity and the environment (Herutomo & Istiyanto, 2021).

Threats to forest sustainability, such as deforestation, wildfires, and illegal encroachment, are increasing, while conventional monitoring methods often fall short in providing accurate and real-time data, especially in vast and hard-to-reach areas. With the rapid development of digital technology, the use of drones and artificial intelligence (AI) offers new opportunities to improve forest monitoring efficiency. Drones enable faster and more flexible monitoring, while AI plays a role in analyzing collected data to detect threats such as fires or illegal encroachment more accurately and promptly. Challenges such as high costs and technical limitations of drones must be addressed to maximize the application of this technology. This study aims to explore the application of drones and AI in forest conservation, assess their effectiveness in threat detection, and provide insights into how these technologies can enhance more responsive and sustainable forest management.

The advancement of digital technology has significantly impacted the forestry sector, which is now facing increasingly complex conservation challenges (Sukmayana, 2023). Previously, forest management was done manually and limited by available human resources. However, with the emergence of new technologies, monitoring efficiency and effectiveness have greatly improved. One of the most important innovations in this field is the use of drones and artificial intelligence (AI), which are increasingly becoming innovative solutions in forest management and conservation. These technologies enable real-time forest monitoring with broader and more accurate coverage while reducing resource limitations. For instance, drones can collect data from remote forest areas, providing a clearer picture of forest cover conditions and potential threats such as fires or illegal logging. With their ability to fly low and flexibility in image capturing, drones can gather visual data that is later analyzed to detect changes occurring in forest areas. Another advantage is their ability to reach areas inaccessible to human monitoring, thus expanding surveillance coverage and allowing for quicker responses to threats to forest ecosystems.

Artificial intelligence (AI) also plays a vital role in improving forest management efficiency (Krisprimandoyo, 2024). AI can analyze big data collected from various sources, such as satellite images, drones, and sensors installed within forests. By using machine learning algorithms, AI can detect patterns or changes in forest ecosystems that might be difficult for humans to perceive, such as gradual degradation or emerging environmental threats (Febriyanto et al., 2022). Moreover, AI can predict long-term trends based on historical data, assisting in the development of more targeted and effective conservation strategies. The use of this technology enables more data-driven, integrated, and responsive forest management based on field dynamics (Mas'ud et al., 2024).

Drone technology, with its low-altitude flying capability and aerial imaging, has revolutionized the way forests are monitored and managed. Previously, forest monitoring relied on direct observation or satellite imagery, which, though effective, often faced

limitations in image resolution and data processing speed. Satellite imagery also does not always provide current information about on-the-ground changes, as data updates can be time-consuming and costly (Astaman et al., 2021). In this regard, drones offer a more efficient and flexible solution by producing real-time, high-resolution images and accessing areas difficult for humans or other technologies to reach.

Drones can be equipped with various sensors, such as multispectral cameras, LiDAR, or infrared sensors, enabling more comprehensive data collection (Nina, 2023). For example, multispectral cameras can detect plant health and vegetation cover, while LiDAR provides highly detailed topographic data, including land contours and forest structure. This information is crucial for mapping potential forest threats such as fires, deforestation, or damage caused by illegal logging (Siregar, 2020). With this technology, drones can provide more accurate and up-to-date data compared to traditional observation methods, allowing authorities to respond more quickly to emerging issues (Parung et al., 2021).

A major advantage of using drones in forest monitoring is their ability to conduct real-time surveillance in difficult-to-access conditions, such as remote areas or regions affected by natural disasters (Putera et al., 2023). In locations unreachable by vehicles or people, drones can deliver immediate visual assessments without disturbing the forest ecosystem. Furthermore, drones are more cost-effective than deploying field teams or using aircraft. This capability allows for more sustainable monitoring and accelerates decision-making in forest conservation efforts (Lasaiba, 2023). With their various capabilities and flexibility, drones can be highly effective tools in strengthening global forest preservation efforts.

Using drones in forest monitoring provides significant advantages in terms of cost and time efficiency, especially when compared to manual data collection methods that require extensive labor, resources, and time (Buana et al., 2024). Previously, large-scale forest monitoring required sizable field teams conducting direct surveys or using more expensive and time-consuming traditional monitoring tools. In this context, drones offer a more cost-effective and faster solution by automating data collection procedures more efficiently (Sulartopo et al., 2023). Drone operational costs are also lower than deploying expeditions to remote areas or using aircraft for aerial surveys.

Drones enable continuous data collection at higher frequencies, making them superior in detecting rapid forest changes. For instance, changes in forest cover, fire outbreaks, illegal encroachment, or damage from natural disasters can be detected more quickly thanks to drones' real-time monitoring abilities. Data collected by drones can be immediately analyzed to provide up-to-date forest condition information, enabling authorities or forest managers to promptly take preventive or corrective actions. This is crucial to preventing further damage or negative impacts on already fragile ecosystems.

The speed and effectiveness of drone use also offer flexibility in responding to urgent situations. For example, in the case of forest fires, drones can monitor smoke-exposed or burning areas directly and provide more accurate visuals of fire locations and spread. The data collected helps emergency teams plan firefighting efforts more efficiently and strategically. These advantages make drones invaluable in modern forest management, not only speeding up monitoring processes but also enabling faster and more targeted responses to existing threats.

Artificial intelligence (AI) plays an essential role in processing and analyzing data collected by drones during forest monitoring. With advanced algorithms, AI can recognize patterns, detect unexpected changes, and predict threats to forest sustainability.

AI's key strength lies in its ability to analyze large volumes of images and data with high accuracy, which is far more efficient than manual observation. For example, AI can detect forest fires, illegal encroachment, or vegetation decline faster and more accurately than conventional methods. One critical application of drone and AI technology in forestry is monitoring forest fire damage. Forest fires, especially in tropical regions, can cause massive ecological damage. Drones allow firefighting personnel to monitor affected areas directly from the air, identify fire hotspots, and plan suppression strategies more effectively. Meanwhile, AI can analyze fire data from various angles, such as determining fire severity and environmental impact, enabling more accurate and timely disaster mitigation responses.

Drone and AI technologies also support sustainable forest management (Swasono et al., 2023). By regularly monitoring forest conditions, drones can identify time-based changes, providing essential insights for forest managers in making informed policy decisions. AI processes this data to provide accurate analysis-based recommendations, aiding decision-makers in planning necessary actions to preserve forest ecosystem balance and prevent further damage. This technology-based approach offers more comprehensive and proactive insights into natural resource management. These technologies also support biodiversity conservation by helping monitor the habitats of forest-dependent species (Suryana & Antara, 2021). Habitat loss due to ecosystem degradation is a significant threat to many endangered plant and animal species. With drone technology, data on species distribution and habitat conditions can be collected more efficiently. AI can then analyze this data to map potential threats to endangered species, allowing for more targeted protection efforts. With these advances, drone and AI technology offer efficient, data-driven solutions to major forest conservation and environmental sustainability challenges in the future.

However, the implementation of drone and artificial intelligence (AI) technologies in forest conservation faces challenges related to environmental variations across forest types. Most research has focused on monitoring forests with specific characteristics, such as lowland or relatively intact forests, while the application of these technologies in tropical, mountainous, or degraded forests remains limited. Each forest type has unique features that affect drone and AI performance, such as vegetation density, extreme weather, or difficult terrain. Further research is needed to evaluate how environmental and geographical factors influence the effectiveness of these technologies in threat detection and efficient forest management (Sidik & Juliana, 2024). For instance, in tropical forests with dense vegetation, drones may have limited image capture capability, while in mountainous forests, hilly terrain may affect drone stability. AI must also adapt to complex data variations, such as differences in vegetation types and climate conditions. Therefore, developing more specialized AI models and enhancing drone capabilities for diverse terrains is crucial to enabling broader and more effective application of these technologies in global forest conservation.

METHODOLOGY

This study employs a literature review approach to explore the application of drone technology and artificial intelligence (AI) in forest conservation. Data were collected from various relevant sources, such as scientific journals, research reports, and conference articles, with a focus on the implementation of these technologies in forest monitoring and management. The analysis was conducted using thematic analysis,

grouping data based on key themes, such as the use of drones for forest monitoring, AI applications in data analysis, technological challenges and successes, and socio-economic impacts. A critical evaluation of the literature aims to identify shortcomings and challenges in the application of these technologies, as well as to provide recommendations that can optimize forest management. Through this literature review, the study is expected to offer in-depth insights into the potential of drone and AI technologies in forest conservation and to identify knowledge gaps that need to be addressed in future research.

RESULTS AND DISCUSSION

The utilization of drone technology and artificial intelligence (AI) in forest conservation offers significant advancements in managing natural resources more efficiently and responsively. Drones, with their ability to reach vast and remote forest areas, enable faster and broader monitoring than conventional methods (Fiqri, 2024). Previously, overseeing large and inaccessible forests required tremendous physical effort and lengthy time. With drone technology, data collection can be conducted directly and in real time, allowing immediate action against threats such as wildfires, illegal encroachment, or significant vegetation changes. These benefits enhance responsiveness to emerging issues in a faster and more coordinated manner.

Artificial intelligence (AI) plays a key role in processing and analyzing data collected by drones, enabling problem identification more efficiently and accurately (Ahadiyat et al., 2023). AI is capable of analyzing large volumes of images and data at speeds far higher than manual observation, making it easier to detect unexpected changes. For example, AI can accurately detect wildfires, illegal encroachment, or vegetation quality decline. This technology not only accelerates the analysis process but also provides deeper insights into forest conditions, which can be used for more precise, data-driven decision-making.

The capacity of drones to capture aerial visuals and real-time data, combined with AI-driven analysis, also allows for more detailed and sustained monitoring (Saiqul et al., 2023). With real-time data availability, forest managers can promptly respond to threats without waiting for time-consuming reports or field surveys. This is crucial for tackling rapid threats like fast-spreading wildfires or illegal deforestation that are difficult to detect without intensive monitoring. Through the use of this technology, forest management becomes more proactive and responsive to on-the-ground dynamics.

This technology also enables more sustainable forest management by monitoring ecosystem conditions over time. Drone-collected data such as vegetation distribution or soil quality changes can be analyzed by AI to identify patterns signaling potential ecological issues. This supports decision-makers in planning mitigation strategies that are more targeted and grounded in accurate data. Thus, drone and AI technologies not only enhance monitoring efficiency but also contribute significantly to more sustainable forest management and conservation (Uhai et al., 2024).

The combination of drone and AI technology further strengthens the effectiveness of forest monitoring by enabling more efficient and responsive management of threats to forest ecosystems. AI functions as a vital data processor, employing machine learning algorithms to analyze drone-acquired data with much greater speed and accuracy than traditional methods. Visual data captured by drones such as images or videos of extensive forest areas can be analyzed by AI to detect significant change patterns, like shifts in vegetation structure indicating damage or environmental stress, or to detect ongoing

wildfires. This allows earlier problem identification, which enhances the ability to respond quickly and prevent wider ecosystem damage.

AI also has the capability to process large data volumes without human time and labor constraints (Ramadhina et al., 2023). Previously, monitoring vast and remote forests required extensive field data collection relying on large human resource investments, with slow and error-prone analysis processes. With drone technology, data can be gathered in real time and directly analyzed by AI to offer a more complete and in-depth overview. This large-scale data processing enables more comprehensive analysis, including the identification of subtle or hidden issues that manual methods might miss. For example, AI can spot minor changes in vegetation or soil patterns that may serve as early indicators of illegal encroachment or undetected fire damage.

AI's ability to learn from historical data and existing patterns allows the system to make more accurate predictions about potential future threats. Based on analyzed data, AI can estimate trends in ecosystem change, such as forest degradation or local climate shifts affecting biodiversity (Muin, 2023). These predictions give authorities and forest managers more lead time to plan effective mitigation or preventive strategies. In cases of wildfires, for instance, AI can help predict fire spread paths based on weather and vegetation data, enabling more efficient firefighting strategies to be implemented promptly.

The integration of drone and AI also enhances long-term sustainable monitoring. With systems continuously gathering and analyzing data, not only current issues are identified, but also minor changes that may affect ecosystem balance over time. Through these technologies, forest monitoring becomes more effective, involves less field-team labor, and is more responsive to evolving threats. Drone and AI enable a proactive rather than reactive conservation approach, essential for preserving forests and biodiversity in the modern era.

CONCLUSION

The utilization of drone technology and artificial intelligence (AI) in forest conservation has brought significant positive impacts in efforts to sustainably preserve and manage forests. Drones, with their real-time monitoring capabilities and access to remote or hard-to-reach areas, enable rapid and detailed data collection on forest conditions. Meanwhile, artificial intelligence supports efficient data analysis, identifying patterns or threats that could potentially damage forest ecosystems, such as wildfires, illegal encroachment, and vegetation changes. The use of this technology accelerates decision-making, allowing authorities to respond to forest threats more swiftly and accurately. Moreover, the combination of drones and AI can minimize operational costs while providing more accurate and continuous data to support evidence-based conservation policies. However, challenges remain, such as high implementation costs, technical limitations of drones, and the need for high-quality data for AI systems. Collaborative support from governments, research institutions, and local communities is essential to address these challenges. With such support, drone and AI technologies have the potential to become key solutions in ensuring forest sustainability and protecting the biodiversity within, making a tangible contribution to global environmental conservation efforts.

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