IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 12, Issue 11, November 2025

DOI: 10.17148/IARJSET.2025.121115

Autonomous Aerial Systems For Precision-Based Forest Reforestation

ROOPA K MURTHY[1], APOORVA V KULKARNI[2], CHANDANA S RAO[3], SHREYA C S[4], VINUTHA S[5]

Assistant Professor, Computer Science and Design, K. S. Institute of Technology, Bengaluru, India[1]

Students, Computer Science and Design, K. S. Institute of Technology, Bengaluru, India[2-5]

Abstract: Contemporary silvicultural restoration has witnessed substantial technological advancement through Unmanned Aerial Vehicle (UAV) integration, representing a significant departure from labour-intensive methodologies and mechanised approaches compromising ecological integrity. Notable developments include ultralight pneumatic seedling deployment systems (under 25 kilograms) employing compressed air propulsion with telescoping actuators for placement and soil consolidation. Modular geospatial control frameworks optimize seed distribution by distinguishing suitable planting zones, demonstrating potential 40% reductions in resource expenditure, while gravity-assisted dispersal mechanisms with pulse-width modulation enable precision applications.

Site selection employs convolutional neural networks, achieving classification accuracies exceeding 93% across land cover categories. Post-establishment monitoring utilizes photogrammetric algorithms to quantify canopy metrics and enumerate saplings from UAV imagery, particularly valuable in telecommunications-limited regions. Three-dimensional photogrammetric reconstruction integrated with geographic information systems enables comprehensive visualization and quantitative assessment, supporting evidence-based management strategies that minimize soil disruption and enhance pedological characteristics conducive to vegetation establishment in disturbed landscapes.

Keywords: Drone Reforestation, Unmanned Aerial Vehicles (UAVs), Seedling Planting Mechanism, Deep Learning, Geospatial Data, Forest Management

I. INTRODUCTION

Escalating environmental degradation driven by widespread deforestation and anthropogenic climate disruption has necessitated the development of efficient, scalable, and ecologically sustainable silvicultural restoration methodologies. Conventional afforestation approaches, characterized by manual labour requirements and intensive resource allocation, encounter substantial economic constraints, workforce limitations, and scalability challenges. Mechanised alternatives, predominantly utilising heavy terrestrial equipment such as hydraulic excavator-mounted insertion devices, remain restricted to topographically uniform, vegetation-cleared sites while inducing considerable pedological disturbance and proving economically prohibitive for small-scale operations or complex terrain configurations.

Addressing these operational limitations, contemporary research emphasizes the application of Unmanned Aerial Vehicle (UAV) platforms for ecological restoration and precision forestry applications, effectively circumventing constraints imposed by irregular topography and dense vegetation cover. Current investigations encompass integrated aerial systems addressing multiple restoration phases, including propagule deployment, seed distribution, site characterization, and post-establishment assessment.

Significant technological progress is exemplified by aerial seedling insertion platforms employing ultralight mechanisms (approximately 15 kilograms excluding power systems) that utilize double-telescoping architectures combined with pneumatic propulsion systems. These configurations penetrate substrate surfaces, deposit containerised seedlings, and consolidate surrounding soil matrices without inducing surface degradation. Innovative passive compression mechanisms redirect vertical forces laterally, ensuring adequate soil consolidation critical for seedling establishment, particularly in regions experiencing freeze-thaw cycling.

Concurrent developments have enhanced seed dispersal precision through modular geospatial control systems. By integrating cartographic data differentiating viable from unsuitable planting zones, pulse-width modulation protocols regulate seed release mechanisms, demonstrating potential reductions in propagule wastage approaching 40% during

DOI: 10.17148/IARJSET.2025.121115

experimental trials by eliminating distribution in inappropriate locations. Alternative gravity-based dispersal prototypes feature adjustable flow regulation suitable for controlled precision agricultural applications.

UAV platforms additionally facilitate site selection and monitoring through advanced computational analysis. Deep learning architectures, including densely connected convolutional networks, enable rapid terrain classification from aerial imagery, achieving accuracies exceeding 93% across multiple land cover categories including degraded forest zones and exposed lithological features, thereby identifying optimal planting locations. Post-establishment monitoring employs photogrammetric processing algorithms that quantify canopy metrics and enumerate individual saplings through spectral analysis and morphological detection techniques, providing essential quantitative data for conservation organizations operating in telecommunications-limited regions.

For complex restoration scenarios such as post-extraction landscape rehabilitation, three-dimensional spatial planning methodologies integrate oblique photogrammetry with geographic information systems, transforming conventional planar designs into volumetric models. These approaches enable comprehensive visual and quantitative landscape change assessment while supporting management strategies emphasizing minimal soil disruption to enhance pedological characteristics. Collectively, these advances demonstrate the transformative potential of integrated aerial robotics and computational science in establishing more efficient, precise, and sustainable forest restoration practices globally.

II. LITERATURE REVIEW

Serial No.	Year of Publication	Project Title	Description
1	2025 [1]	An Ultra-Light Seedling Planting Mechanism for Use in Aerial Reforestation	Contemporary aerial reforestation research has introduced pneumatically-actuated planting mechanisms designed for UAV deployment. One notable system features an ultralight apparatus (approximately 8 kilograms) employing compressed air propulsion through a double-telescoping actuator design. This configuration enables sequential substrate penetration, seedling insertion, and soil consolidation in a single operational cycle. The pneumatic system generates instantaneous high-magnitude forces adequate for effective soil penetration while maintaining compatibility with small-scale UAV platforms, offering superior power-to-weight ratios compared to electromagnetic or hydraulic alternatives. This approach eliminates reliance on multi-ton terrestrial equipment, thereby reducing operational costs, removing vehicular accessibility constraints, and minimizing ecological disturbance to surrounding soil and vegetation. The lightweight design facilitates deployment across challenging topographic conditions—including steep gradients and irregular post-disturbance terrain—previously inaccessible to conventional mechanized planting operations, representing a significant advancement in scalable reforestation technology. [1]
2	2025 [2]	SkyPlanter: Aerial Reforestation with an Ultralight, Seedling–Planting Drone	Recent advancements in Unmanned Aerial Vehicle technology have enabled the development of drone-based systems for planting tree seedlings aerially. This innovation addresses critical forestry challenges where conventional manual methods require substantial investment and intensive labour, while mechanized alternatives depend on heavy excavation equipment that damages soil and operates only on level terrain. The drone approach navigates challenging topography inaccessible to ground machinery. The apparatus weighs 15.2 kilograms excluding power sources, achieving lightness through a double-telescoping structure channelling forces through one central component and a compressed air propulsion system (100-300 bar), generating rapid movements for soil penetration. Mounted on a quadrotor with the mechanism positioned through the aircraft's centre of mass, the system executes planting in four phases: touchdown, dibber insertion, seedling release, and soil compaction using a passive

DOI: 10.17148/IARJSET.2025.121115

			pincer design. Field testing demonstrated successful Norwegian spruce plantation, completing cycles in approximately nine seconds with potential to exceed manual planting productivity.[2]
3	2023 [3]	Modular Seed-Sowing Control System for Drone Reforestation	Emerging precision technologies in aerial reforestation have led to sensor-integrated control systems designed to enhance sowing efficiency and seedling establishment rates, addressing substantial seed wastage and poor germination from non-targeted dispersal methods in conventional drone operations. A notable advancement features modular architecture, allowing the control unit and dispensing mechanism to function independently from the Unmanned Aerial Vehicle platform, ensuring compatibility across diverse aircraft models. The control unit incorporates dedicated Global Positioning System and Inertial Measurement Unit sensors, maintaining wireless communication with ground-based computers storing pre-processed cartographic data, distinguishing suitable planting zones. During operation, the controller evaluates the aircraft's geographical position against spatial information and employs Pulse Width Modulation signals to activate dispersal exclusively over designated areas. Validation trials demonstrated approximately 40% reduction in seed consumption compared to systems lacking spatial awareness. This optimisation proves valuable for expensive pelleted seed formulations, maximising coverage area estimated at 2,070 square meters per flight at maximum capacity through autonomous operations.[3]
4	2023 [4]	Seed Spreading UAV Prototype for Precision Agriculture Development	Advancements in precision agriculture have driven the development of unmanned aerial vehicle prototypes for rapid seed distribution. One system was conceptualised through computer-aided design software, with components fabricated using additive manufacturing and laser techniques. The primary innovation involves a servo-actuated dispersal mechanism enabling dynamic hopper aperture adjustment during flight, permitting precise regulation of seed quantity and release timing. The assembled quadcopter achieves 2.4 kilograms total mass, accommodates 150 grams of seed payload, and maintains 10 kilometres per hour operational velocity. This approach demonstrates potential for optimising agricultural input utilisation while minimising manual labour, presenting value as an economically accessible solution for Central American farming communities. Further development incorporating Global Positioning System navigation and autonomous flight capabilities would substantially enhance operational stability and expand functional versatility for practical deployment.[4]
5	2021 [5]	Reforestation Using Drones and Deep Learning Techniques	Contemporary approaches to combating deforestation have explored automated aerial platforms for efficient seed distribution, achieving speeds approximately nine times greater than conventional manual planting while improving operational efficiency and safety in remote regions. Comparative analysis of deep learning architectures, including MobileNetV2, DenseNet121, and ResNet152, evaluated terrain classification for plantation suitability. DenseNet121 demonstrated superior performance with 93.1% accuracy across categories, including deforested areas, existing forest cover, and rocky unsuitable terrain. The hardware configuration integrates an APM 2.8 flight control system with Raspberry Pi Model B+ processing to execute classification algorithms and regulate seed dispensing mechanisms. This integration exemplifies the practical application of Artificial

DOI: 10.17148/IARJSET.2025.121115

			Intelligence for addressing environmental challenges through real-time decision-making during autonomous reforestation operations.[5]
6	2021 [6]	Seed Dispenser using Drones and Deep Learning Techniques for Reforestation	An integrated aerial seeding platform has been developed incorporating embedded computational vision capabilities for autonomous site identification. The system employs a mechanical dispensing apparatus comprising funnel architecture and servo-actuated release mechanisms, coupled with MobileNet deep learning framework deployed on embedded Raspberry Pi hardware. The computational model performs real-time object detection to enable operator-assisted identification of deforested zones requiring intervention, designated as target deployment areas. This integration facilitates precision seed distribution exclusively identifies restoration sites, enhancing operational efficiency by eliminating dispersal over unsuitable terrain. The approach demonstrates particular utility in post-disturbance landscape rehabilitation following natural catastrophic events such as wildfire incidents, enabling targeted resource allocation towards degraded areas requiring ecological restoration interventions. [6]
7	2020 [7]	Research on 3D Real Scene Planning Method for Mine Reforestation	A novel three-dimensional spatial planning methodology for post-mining landscape restoration has been proposed through the integration of UAV oblique photography and 3D Geographic Information System (GIS) technology. It transforms traditional 2D designs into accurate 3D models, enabling the integration of the reforestation plan with the real scene mining model. This facilitates visual and quantitative assessment of landscape changes and aids optimal restoration decision-making.[7]
8	2019 [8]	UAV Image Processing Algorithms for Analysing Reforestation Efforts in Tanzania	An algorithmic framework employing standard UAV RGB imagery has been developed to monitor reforestation efforts for non-profit organizations operating in areas with limited internet access, such as Tanzania. The computational scripts calculate quantifiable metrics essential for restoration assessment, specifically percent canopy coverage through Hue Saturation Value (HSV) colour space analysis and young tree enumeration via blob detection combined with image thresholding techniques. This approach enables local data processing without requiring continuous network connectivity, facilitating real-time monitoring and assessment of plantation establishment success rates in remote operational environments.[8]

III. CONCLUSION

Contemporary research demonstrates a systematic convergence toward automated, data-driven approaches in global reforestation through integrated unmanned aerial systems and computational analytics. This technological paradigm addresses the fundamental limitations of conventional afforestation methodologies, including labour intensity, economic constraints, terrain accessibility restrictions, and ecological disturbances associated with mechanised ground-based operations. Hardware innovations centre on ultralight pneumatic deployment mechanisms (8-15 kilograms operational mass) employing compressed air propulsion and telescoping architectures for substrate penetration, seedling insertion, and soil consolidation across diverse topographic conditions. Complementing these systems, precision seed distribution frameworks utilize geospatial control and pulse-width modulation protocols, demonstrating potential reductions in propagule wastage approaching 40%, while gravity-based alternatives enable adjustable flow control for broadcast applications.

Computational analysis of UAV-acquired imagery facilitates both site selection and post-establishment monitoring. Deep learning architectures achieve classification accuracies exceeding 93% across terrain categories, enabling autonomous identification of optimal planting locations. Photogrammetric algorithms quantify canopy metrics and enumerate individual saplings, providing essential assessment data for conservation organisations in regions with limited telecommunications. Three-dimensional spatial planning integrating oblique photogrammetry with geographic

DOI: 10.17148/IARJSET.2025.121115

information systems enables comprehensive visualization and quantitative assessment in complex post-disturbance landscapes.

These technological advances signify a fundamental transition toward integrated autonomous systems characterised by enhanced operational efficiency, resource optimization, and improved scalability. The synthesis of lightweight deployment mechanisms, precision distribution control, and advanced computational analytics establishes a robust framework for addressing global deforestation challenges through economically viable, ecologically sound restoration practices capable of mitigating climate change impacts and restoring degraded ecosystems globally.

IV. SUSTAINABLE DEVELOPMENT GOALS

SDG Goals	Goal Description	Justification
SDG 15: Life on Land	Protect, restore, and promote sustainable use of terrestrial ecosystems, forests, forests, and biodiversity	Direct forest restoration; biodiversity; India's 26M hectare target.
SDG 13: Climate Action	Take urgent action to combat climate change and its impacts	Carbon sequestration; India's 2.5-3B tonne CO2 commitment.
SDG 9: Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	AI, robotics, IoT innovation; technological infrastructure.
SDG 8: Decent Work and Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	Economic efficiency; addresses labor shortages.

REFERENCES

[1]. S. Lloyd and R. Astrup, "An Ultra-Light Seedling Planting Mechanism for Use in Aerial Reforestation," 2025 IEEE International Conference on Robotics and Automation (ICRA), Atlanta, GA, USA, 2025, pp. 1474-1480, doi: 10.1109/ICRA55743.2025.11128303.

[2]. S. Lloyd, T. K. Opstrup, E. S. M. Ebeid and R. Astrup, "SkyPlanter: Aerial Reforestation With an Ultralight, Seedling–Planting Drone," in IEEE/ASME Transactions on Mechatronics, doi: 10.1109/TMECH.2025.3606620.

[3]. E. Maldonado, C. Lozoya, C. Gonzalez-Espinoza and L. Orona, "Modular seed-sowing control system for drone reforestation," 2025 IEEE Conference on Technologies for Sustainability (SusTech), Los Angeles, CA, USA, 2025, pp. 1-6, doi: 10.1109/SusTech63138.2025.11025743.

[4]. A. Bonilla-Marquez, O. Guzman-Flores, Y. Rodriguez-Gallo and K. Pimentel-Hernandez, "Seed Spreading UAV Prototype for Precision Agriculture Development," 2024 IEEE Central America and Panama Student Conference (CONESCAPAN), Panama, Panama, 2024, pp. 1-6, doi: 10.1109/CONESCAPAN62181.2024.10891104.

[5]. G. V. S. Lohit, "Reforestation Using Drones and Deep Learning Techniques," 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India, 2021, pp. 847-852, doi: 10.1109/ICACCS51430.2021.9442053.

[6]. G. V. S. Lohit and D. Bisht, "Seed Dispenser using Drones and Deep Learning Techniques for Reforestation," 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2021, pp. 1275-1283, doi: 10.1109/ICCMC51019.2021.9418227.

[7]. F. Tang, Z. Ruan, M. Chen, J. Hu and T. Tang, "Research on 3D Real Scene Planning Method for Mine Reforestation," IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, Waikoloa, HI, USA, 2020, pp. 889-892, doi: 10.1109/IGARSS39084.2020.9323419

[8]. S. Bucher, C. Kitts, M. A. Neumann and J. M. Tritchler, "UAV Image Processing Algorithms for Analyzing Reforestation Efforts in Tanzania," 2019 IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 2019, pp. 1-4, doi: 10.1109/GHTC46095.2019.9033028.