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Aerial Intelligence and ICT: Transforming Forestry and Agroforestry through Drone Technology

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ABSTRACT: The integration of Information and Communication Technology (ICT) with unmanned aerial vehicles (UAVs), commonly known as drones, has introduced a new paradigm of aerial intelligence in forestry and agroforestry. ICT-enabled drone systems combine advanced sensors, geospatial technologies, data analytics, and decision support tools to enhance forest resource assessment, agroforestry planning, and silvicultural management. This article examines the role of drones as an aerial intelligence platform in forestry, highlighting their applications in resource inventory, biomass and carbon estimation, vegetation health monitoring, agroforestry system optimization, and silvicultural operations. Emphasis is placed on how ICT transforms drone-derived data into actionable knowledge through GIS, remote sensing, artificial intelligence, and cloud-based information systems. The article synthesizes existing research and practical experiences to demonstrate that drone-based aerial intelligence supports sustainable forest management, climate-smart agroforestry, and precision silviculture by improving accuracy, efficiency, and timeliness of decision-making.

KEYWORDS: Aerial intelligence, ICT, drones, UAV, forestry, agroforestry, silviculture, resource assessment, GIS, remote sensing

I. INTRODUCTION

Forestry and agroforestry systems play a critical role in ecological stability, biodiversity conservation, climate regulation, and rural livelihoods. Effective management of these systems depends on accurate and timely information on forest resources, vegetation health, growth dynamics, and environmental stresses. Conventional forest inventory and monitoring methods, largely based on ground surveys and manual measurements, are often constrained by high costs, limited spatial coverage, difficult terrain, and delayed data availability. With increasing pressures from climate change, land-use change, forest degradation, and the need for sustainable intensification of agroforestry systems, there is a growing demand for innovative, technology-driven approaches to forest management.

Information and Communication Technology (ICT) has emerged as a key enabler of transformation in natural resource management. Among ICT tools, drone technology has gained prominence due to its ability to capture high-resolution, site-specific, and real-time spatial data. When integrated with GIS, remote sensing, artificial intelligence, and decision-support systems, drones form the backbone of what is now termed aerial intelligence— the process of collecting, analysing, and applying aerial data to support informed management decisions. In forestry and agroforestry, aerial intelligence bridges the gap between field observations and strategic planning by offering a synoptic yet detailed view of landscapes.

This article presents a comprehensive discussion on ICT-enabled drone applications in forestry resource assessment and agroforestry silviculture. It explores how aerial intelligence improves inventory accuracy, supports precision management, and contributes to sustainable and climate-resilient forestry practices.

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II. REVIEW OF THE LITERATURE

The literature reveals that the application of ICT-enabled drone technology in forestry has emerged as a significant advancement over conventional ground-based and satellite-driven methods. Numerous studies report that UAVs equipped with RGB, multispectral, and LiDAR sensors provide high-resolution, timely, and spatially explicit information for forest resource assessment, including forest cover mapping, stand structure analysis, biomass estimation, and carbon stock assessment (Anderson & Gaston, 2013; Tang & Shao, 2015). Research further indicates that drone-derived vegetation indices show strong correlations with field-measured parameters, validating their effectiveness in monitoring forest health and productivity (Dash et al., 2017). In agroforestry contexts, scholars have demonstrated that UAV imagery supports detailed analysis of tree–crop interactions, spatial heterogeneity, and stress detection, thereby facilitating precision management and improved silvicultural decision-making (Laliberte & Rango, 2011; Pádua et al., 2017). More recent studies emphasize the integration of UAV data with GIS, artificial intelligence, and cloud-based platforms, which enhances automated interpretation, decision support, and long-term monitoring, confirming aerial intelligence as a robust and sustainable approach for modern forestry and agroforestry management (Jayathunga et al., 2018).

Concept of Aerial Intelligence and ICT Integration

Aerial intelligence refers to the systematic acquisition of aerial data using drones and the transformation of this data into meaningful information through ICT frameworks. Drones act as mobile data acquisition platforms, while ICT components—such as GNSS, GIS, remote sensing software, cloud computing, and artificial intelligence— enable data processing, analysis, storage, and dissemination. The intelligence component lies not merely in data collection, but in the interpretation and application of information to guide management decisions.

In forestry, ICT integration ensures that drone-derived data are georeferenced, standardized, and interoperable with existing forest management information systems. High-resolution imagery captured by UAVs is processed into orthomosaic, digital elevation models, and vegetation indices using specialized software. These outputs are then analysed within GIS environments, allowing spatial analysis of forest structure, health, and change dynamics. Machine learning algorithms further automate tasks such as tree detection, species classification, and stress identification. Thus, aerial intelligence represents a convergence of hardware, software, and analytical capacity aimed at enhancing decision-making efficiency and accuracy.

Objectives (Point-wise with citation extract)

1. **To review the role of ICT-enabled drone technology in forestry resource assessment**, with emphasis on forest cover mapping, stand structure analysis, and inventory accuracy as reported in recent studies (Anderson & Gaston, 2013; Tang & Shao, 2015).
2. **To examine the effectiveness of UAV-based sensors (RGB, multispectral, LiDAR)** for estimating vegetation health, biomass, and carbon stocks in different forest ecosystems (Dash et al., 2017; Jayathunga et al., 2018).
3. **To assess the application of drones in agroforestry systems** for analysing tree–crop spatial interactions, canopy dynamics, and crop stress detection to support precision management practices (Laliberte & Rango, 2011; Pádua et al., 2017).
4. **To evaluate the contribution of drone-based aerial intelligence to silvicultural operations**, including regeneration monitoring, thinning assessment, and post-disturbance evaluation (Tang & Shao, 2015).
5. **To analyse the integration of UAV data with GIS, artificial intelligence, and decision-support systems** for enhancing automated analysis, spatial planning, and sustainable forestry management (Pádua et al., 2017; Jayathunga et al., 2018).

III. ROLE OF DRONES IN AGROFORESTRY ASSESSMENT

Agroforestry systems are spatially complex and dynamic, involving interactions between trees, crops, soil, and climate. Traditional assessment methods often fail to capture this heterogeneity at appropriate spatial scales. ICT enabled drones provide a solution by delivering high-resolution spatial data that reflect the fine-scale variability inherent in agroforestry landscapes.

Drone imagery supports detailed mapping of tree spacing, canopy cover, crop distribution, and alley configurations. This information is critical for evaluating light interception, competition, and complementarity between system components. Multispectral and thermal sensors are particularly useful in detecting crop stress related to water scarcity, nutrient deficiencies, or disease incidence. By identifying stress patterns early, managers can adopt targeted interventions such as localized irrigation, fertilization, or pest management.

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In silvi-pastoral systems, drones assist in monitoring fodder availability, grazing intensity, and tree condition. Thermal imagery helps detect soil moisture variability and animal movement patterns, supporting balanced livestock management. ICT integration ensures that these datasets are analysed in near-real time, enabling adaptive management practices that enhance productivity while conserving natural resources.

Drone Applications in Silviculture

Silviculture focuses on the establishment, growth, composition, and quality of forest stands. Drone-based aerial intelligence supports silvicultural operations across all stages of stand development. During the planning stage, drones provide detailed information on site conditions, topography, and vegetation cover, aiding species selection and plantation design. High-resolution elevation models help assess drainage patterns and erosion risks, which are critical for successful establishment.

In regeneration monitoring, UAVs enable rapid assessment of seedling survival, spacing uniformity, and early growth performance. Multispectral imagery helps distinguish planted seedlings from competing vegetation, facilitating targeted weeding and tending operations. In areas affected by disturbances such as forest fires, storms, or pest outbreaks, drones provide a rapid means of assessing damage extent and regeneration potential, allowing timely restoration measures.

During stand development, aerial intelligence supports thinning and harvesting decisions by providing data on crown competition, canopy closure, and health status. Repeated drone surveys enable growth monitoring and yield estimation over time. ICT-based analysis ensures that silvicultural prescriptions are spatially explicit and evidence-based, reducing uncertainty and improving management outcomes.

ICT-Driven Data Analytics and Decision Support

The true value of drone applications in forestry lies in ICT-driven data analytics and decision support. Large volumes of drone data are processed using automated algorithms to extract meaningful information. Artificial intelligence techniques, including machine learning and deep learning, are increasingly used for tree detection, species identification, and change detection. These approaches reduce manual interpretation effort and increase consistency and scalability.

GIS-based decision support systems integrate drone-derived datasets with ancillary information such as soil maps, climate data, and management records. This integration enables scenario analysis, risk assessment, and prioritization of interventions. For example, areas with low vegetation indices and high fire risk can be identified and targeted for preventive measures. Cloud-based platforms facilitate data sharing and collaboration among researchers, forest managers, and policymakers, enhancing transparency and collective decision-making.

Contribution to Sustainable and Climate-Smart Forestry

Aerial intelligence contributes significantly to sustainable forestry and agroforestry by improving resource-use efficiency and resilience to environmental change. Accurate biomass and carbon stock estimation supports climate mitigation initiatives and reporting requirements. Early detection of stress factors enables proactive management, reducing losses and enhancing system resilience.

Drone-based monitoring reduces reliance on extensive ground surveys, lowering operational costs and minimizing ecological disturbance. In agroforestry, precision management guided by aerial intelligence enhances productivity while maintaining ecological functions such as soil conservation, biodiversity support, and microclimate regulation. Thus, ICT-enabled drones align forestry and agroforestry practices with sustainability and climate-smart development goals.

IV. CHALLENGES

1. Limited battery life and payload capacity of UAVs restrict flight duration and sensor integration in large or dense forest areas (Anderson & Gaston, 2013).
2. High initial costs of advanced sensors, data processing software, and ICT infrastructure limit widespread adoption, particularly in developing regions (Pádua et al., 2017).
3. Regulatory restrictions and airspace permissions constrain operational flexibility of drone deployments in forest landscapes (Tang & Shao, 2015).
4. Requirement of skilled personnel for flight operations, data processing, and interpretation creates capacity gaps in forestry institutions (Laliberte & Rango, 2011).

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5. Large data volumes generated by UAVs pose challenges related to data storage, processing speed, and long-term management (Dash et al., 2017).
6. Variability in lighting conditions, canopy density, and terrain complexity affects data quality and consistency (Jayathunga et al., 2018).

V. OPPORTUNITIES

1. Advancement in sensor technology and battery efficiency offers potential for longer flights and more accurate forest data collection (Tang & Shao, 2015).
2. Integration of UAV data with GIS, artificial intelligence, and cloud computing enhances automation, scalability, and decision support (Pádua et al., 2017).
3. Increasing demand for carbon stock assessment and climate-smart forestry creates opportunities for drone based biomass monitoring (Jayathunga et al., 2018).
4. Application of drones in agroforestry enables precision management of tree–crop systems, improving productivity and sustainability (Laliberte & Rango, 2011).
5. Community-based and participatory forestry programs can benefit from low-cost UAV platforms for localized monitoring and planning (Anderson & Gaston, 2013).
6. Policy support and technological innovation are expected to mainstream drone-based aerial intelligence into routine forestry and agroforestry operations (Dash et al., 2017).

VI. CONCLUSION

Aerial intelligence enabled by ICT and drone technology has emerged as a transformative force in forestry and agroforestry silviculture. By providing high-resolution, timely, and spatially explicit data, drones enhance forest resource assessment, support precision agroforestry management, and inform silvicultural decision-making. The integration of UAVs with GIS, remote sensing, artificial intelligence, and decision-support systems ensures that data are translated into actionable knowledge. While challenges remain, the continued evolution of ICT and drone technologies holds immense potential for sustainable, efficient, and climate-resilient forestry and agroforestry management.

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