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Review Article

HARNESSING UNMANNED AERIAL VEHICLES AND IT'S SUSTAINABLE FORESTRY MANAGEMENT- SKYWARD SOLUTIONS

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ABSTRACT

This paper delves into the integration of Unmanned Aerial Vehicles (UAVs) for sustainable forestry management, focusing on the innovative solutions offered by Skyward Solutions. It provides an in-depth analysis of the utilization of UAVs in forestry applications, highlighting their potential to revolutionize various aspects of forest management. The discussion encompasses the use of UAVs equipped with advanced sensors and imaging technologies for tasks such as forest monitoring, species detection, and disturbance evaluation. Furthermore, it explores the role of UAVs in facilitating efficient forest inventory management, aiding in the assessment of tree health, biomass estimation, and carbon sequestration monitoring. Key features of Skyward Solutions' UAV platforms and technologies are examined, including their capabilities for high-resolution aerial imaging, LiDAR scanning, and infrared sensing. The paper outlines the benefits of utilizing UAVs in forestry operations, such as increased efficiency, reduced costs, and minimized environmental impact compared to traditional methods. Moreover, the paper discusses the integration of UAV data with Geographic Information Systems (GIS) for comprehensive forest mapping and analysis. It also addresses challenges and limitations associated with UAV implementation in forestry, including regulatory constraints, data processing complexities, and operational considerations. In conclusion, the paper emphasizes the transformative potential of UAVs in advancing sustainable forestry management practices. It underscores the importance of continued research, innovation, and collaboration among stakeholders to harness the full benefits of UAV technology for forest conservation and ecosystem preservation.

Keywords: UAVs, Forestry management, Skyward Solutions, Forest monitoring, Species detection.

INTRODUCTION

For sustainable forest management, precise data on the volume, growth, composition, structure, and extent of forests are necessary. This data can be obtained either from remotely sensed imagery, either directly or indirectly (Shao, 2012). Enhancing forestry applications of remote sensing has garnered more attention during the last few decades. The rise as evidenced by papers in journals with an ISI indices; a search for publications indexed by ISI with the keywords "forest" and "remote sensing" yields one article from the 1960s, four from the 1970s, twenty-four from the 1980s, five36 from the 1990s, twenty-five19 from the 2000s, and 2930 from 2010 to 2014. The swift progress made in civilian satellite remote sensing throughout the 1980s and 1990s are reflected in the sharpest jump in publication numbers that occurred during that time (Boyd and Danson 2005; Shao, 2012). Applications of remote sensing in forestry have changed as sensor and computation technologies have advanced. These include multispectral data-based forest cover mapping (Zhu and Evans 1994; Shao *et al.,* 1996), and satellite imagery-based forest

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resource monitoring (Asner *et al.*, 2005; Tang *et al.*, 2010; Pope *et al.*, 2015), and traditional forest inventories using aerial photography (Lyons 1966). exceedingly spectral From biophysical forest estimations based on data (Martin and Aber 1997; Treitz and Howarth 1999) to characterizations of forest structure based on active remote sensing (Dubayah and Drake 2000; Lefsky *et al.*, 2002) and measurements of the forest leaf area index based on passive remote sensing (Turner *et al.*, 1999; Thakur *et al.*, 2014). It is feasible to enhance estimates of forest volume and biomass by integrating data from several sources (Lu 2006; Koch 2010).

Despite the extensive application of remote sensing there are still forestry technical difficulties. Lack of timely data collection over target areas is one of the biggest obstacles to remote sensing applications in forestry. For example, there may be a lack of suitable satellite imagery and prohibitive aerial photography from crewed/manned aircraft when attempting to evaluate In a forested landscape, pest outbreaks (Wulder *et al.*, 2006) or wildfire spread (Arroyo *et al.*, 2008). Furthermore, although stand-level data is essential According to Zhang and Jim (2013), sustainable forestry cannot be obtained through coarse or remote sensing at a moderate resolution techniques. Adaptable and inexpensive Systems for remote sensing can be used to investigate new applications and enhance current remote sensing capabilities. Although Drones as remote sensing platforms have the potential to increase data acquisition efficiency, though their applications are still in the experimental stage (Ambrosia *et al.*, 2011a; Wing *et al.*, 2013; Shahbazi *et al.*, 2014). Here, we provide a quick summary of the fundamental concepts and early applications of drone-based remote sensing in forestry research with the goal of assisting forestry professionals and researchers in making better use of this new geospatial technology.

Drones as platforms

During the first and second world wars, aircraft took the place of balloons, which were used to take the first aerial photographs in 1860. Following that, the first military satellites were launched into orbit and used in the 1960s and 1970s, respectively, and with the advent of digital sensors, the first civilian uses started to emerge (Banu *et al.*, 2016). Unmanned aerial vehicles, or UAVs, perform a range of tasks without the assistance of a human. They can be controlled remotely by a variety of electronic devices, including sensors and microprocessors (Nourmohamadi *et al.*, 2018). Generally speaking, a UAV is a pilotless aircraft that can operate more cost-effectively than similar manned systems, carry out vital tasks without putting human life in danger, and take off and stay in the air without the need for a human operator (Mohsan *et al.*, 2022). Specifically, major online retailers like Walmart, DHL, Google, and Amazon have shown a great deal of interest in UAVs (Macrinna *et al.*, 2022). Unmanned Aerial Vehicles (UAVs) demonstrate superior maneuverability, cost-effectiveness, self-organization, flexibility, scalability, and ease of deployment (Zhang *et al.*, 2019).

Table 1. Categories of UAV based on No of Propellers.

TYPES OF UAV’S	NO OF PROPELLERS
Octocopter	8
Hexacopter	6
Quadcopter	4
Tricopter	3

Table 2. Key Features of Different Categories of UAV.

Types of UAV’s	Key Features
Fixed wing	High speed, long endurance
Fixed wing hybrid	Long endurance, VTOL
Single rotor	Long endurance, hovering, VTOL
Multi-rotor	Short endurance, hovering, VTOL

Drones, also known as flying robots, include small drones that operate in restricted areas and unmanned aerial vehicles (UAVs) that can travel thousands of kilometers (Krijnen *et al.*, 2014). Drones are defined as aerial vehicles that are operated remotely or autonomously, carry a payload that can be either lethal or nonlethal, and do not have a human operator (Hassanalian *et al.*, 2017). Drones cannot be defined as satellites, cruise missiles, artillery projectiles, mines, torpedoes, and ballistic or semi-ballistic vehicles. While there are numerous types of UAS available today, most of them make use of one or more of: (i) an unmanned aircraft, (iv) a launch and recovery system or flight mechanism, (v) a command and control element, (ii) a sensor payload, (iii) a communication data link, and (vi) most importantly, the human (Cummings *et al.*, 2017). The size and type of installed equipment varies based on the drones' flight missions. Due to the drones' many benefits, numerous studies have been conducted with the goal of optimizing and improving their performance (Sitnikov *et al.*, 2014). Drones have become more and more popular in the past ten years due to their various sizes, shapes, and capabilities. Numerous fields, including forestry, meteorology, biodiversity, precision agriculture, emergency management, land management, and traffic monitoring other civilian applications have all shown an increasing interest in using drones (Shabazi *et al.,* 2014). Utilizing remote sensing techniques in forestry has gained more attention in recent decade, which has made it possible to extract crucial data for sustainable management and forest planning, such as the volume, growth, composition, and structure of the forest. The application of remote sensing in forestry has changed over time, moving from using data from aerial photography to using data from satellite imaging, which has resulted in various outcomes. This evolution coincides with the advancement of sensors, computers, and computational tools.

Classification

Drones are most commonly categorized based on the type of landing and taking off: Horizontal landing and taking is common for aircraft with fixed wings; Vertical takeoff and landing, which is common for drones with rotary wings, such as hexacopters, quadcopters, and helicopters; A drone's stability as well as the region it covers in a single flight are important factors in remote sensing applications. Drones belonging to the first category are able to cover larger areas in a single flight, while drones in the second category have improved stability and can cover smaller areas in a single flight (Tang *et al.,* 2015). Drones can also be categorized according to their power source, which has an immediate impact on their maximum flight duration (Dudek *et al.,* 2013). Regarding this, UAVs can be classified as either internal combustion or electric (Tang *et al.,* 2015). The most common type of classification off UAV'S (Arjomandi *et al.,* 2006).

Classification by performance characteristics, Classification by Weight, Classification by Wing Loading , Classification by Engine Type, Classification by Endurance, Classification by Range and Altitude.

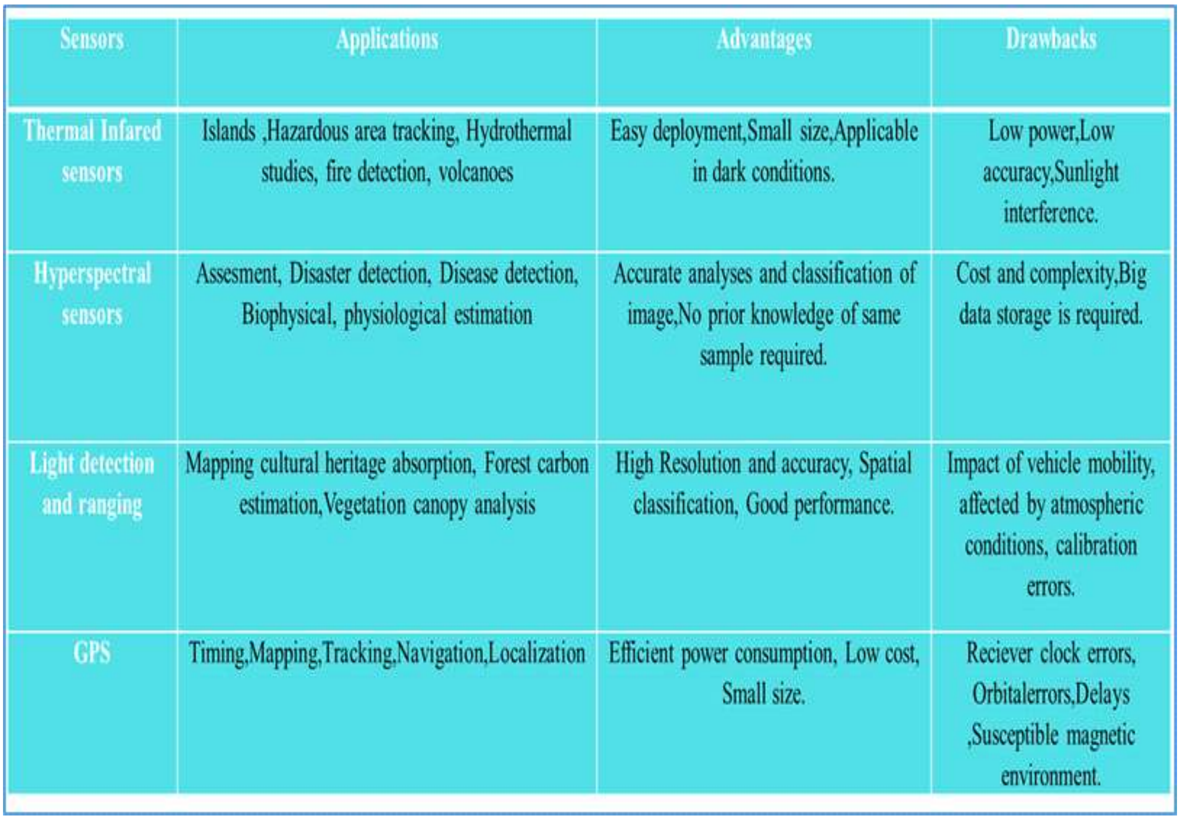
UAV Swarm

In and of itself, swarm technology is not particularly novel. Since the early days of drone development, there have been suggestions for uses and advancements, mainly in the military 1990's (Kelly 1994; Andrew 2017; Condliffe 2017). The Swarming UAVs is still in its early stages despite this. Attention has begun to focus on research, development, and integration efforts for unmanned aerial system (UAS) swarm in more commercial and widespread applications as technology has advanced and become more accessible. Interestingly, Intel developed a swarm of 300 drones that were used in a coordinated light show for both the 2018 Winter Olympics and Super Bowl 51 (Molina 2017). According to Bekmezci *et al*. (2013), the most popular swarm architecture for UAVs is infrastructure-based. Some widely used and easily accessible GCS software has basic swarm capabilities based on infrastructure (Ardupilot, 2018). Infrastructure-based swarming has the benefit of enabling real-time optimization and computations by a GCS through the use of enhanced processing capacity that could be used on a UAS. Furthermore, drones do not need to network with one another, which reduces the amount of payload that is needed (Bekmezci *et al.,* 2013; Sivakumar *et al,* 2010).

In (De Souza *et al*. 2015), The authors address the issue of UAV swarm establishment and upkeep in these mobile network covered areas and suggest a multi-robot coordination algorithm that is bandwidth-efficient for these kinds of situations. In (Lin 2005; Arques 2013; Brust 2015) the authors discuses Swarm behaviors for agent-oriented platforms in multi-robot environments and search and rescue tasks (e.g., in forest conditions). In particular, the authors of (Brust, 2015) address the challenge of creating a network topology and an effective swarm movement model among a group of UAVs that are used especially for the purpose of superior mapping of forests. They proposed a novel solution to the flight problem of UAV swarm formation. The extremely uneven distribution of trees and other obstructions, for example, presents a significant difficulty for a UAV swarm in the forest environment. The swarm must always steer clear of potential tree collisions and adapt on its own the trajectory, which may cause the swarm to disconnect and then re-connect after overcoming the obstacle, all the while gathering environmental data that must be effectively fused and evaluated. The authors of (Varadharajan, 2017) talk about using micro UAS swarms for smooth coordination.

Types of sensors

Using an integrated sensor, the Inertial Guidance System is an electronic system that continuously measures position, velocity, and acceleration set, is essential to drone flight. It is composed of a magnetometer, a 3-axis accelerometer as well as a three- rate gyro. The UAV's attitude is estimated by filtering the IGS readings. The recent advancements in MEMs and computing have resulted in the reduction of IGS sensor dimensions (Kang *et al.*, 2018). Therefore, complete set of sensor readings can be obtained using a micro IGS for small UAVs. Using infrared (IR) thermopile sensors, one can also estimate the information about attitude (Chao *et al.*, 2010). By detecting the temperature differential along one axis between two sensors, they use the fact that the earth emits more infrared radiation than the sky to calculate the UAV's angle. For attitude estimation, additional sensors like vision sensors can be employed alone or in conjunction with inertial measurement sensors (Tang *et al.*, 2018).



Sensors	Applications	Advantages	Drawbacks
Thermal Infared sensors	Islands ,Hazardous area tracking, Hydrothermal studies, fire detection, volcanoes	Easy deployment,Small size,Applicable in dark conditions.	Low power,Low accuracy,Sunlight interference.
Hyperspectral sensors	Assesment, Disaster detection, Disease detection, Biophysical, physiological estimation	Accurate analyses and classification of image,No prior knowledge of same sample required.	Cost and complexity,Big data storage is required.
Light detection and ranging	Mapping cultural heritage absorption, Forest carbon estimation,Vegetation canopy analysis	High Resolution and accuracy, Spatial classification, Good performance.	Impact of vehicle mobility, affected by atmospheric conditions, calibration errors.
GPS	Timing,Mapping,Tracking,Navigation,Localization	Efficient power consumption, Low cost, Small size.	Reciever clock errors, Orbitalerrors,Delays ,Susceptible magnetic environment.

Software

Implementing both software and hardware systems is necessary for instantaneous control. In scholarly works, real-time systems are defined in a number of ways. We found a good definition that goes like this: "In a real-time system, both the logical correctness of a calculation and the time at which the result is made available determine whether the result is correct." (https://www.ibm.com). The system tasks have a deadline that must be met. This deadline is also known as a time requirement. Ensuring a prompt and a predetermined reaction to what happens is the main goal. Such tasks are typically meant to respond in real time to external events in the context of drone control. As a result, these tasks that are being completed in real time are necessary to stay up with external up with external modifications impacting the performance of drones. Hard real-time tasks are those that have deadlines that must be met in order to prevent disastrous outcomes (Wang *et al.,* 2019). A task is deemed soft real-time when it's preferable but not necessary to meet the deadline. Numerous sensing instruments, such as sensors for visible light, thermal infrared (TIR), near infrared (NIR), radar, Lidar, and shortwave infrared (SWIR), can be carried by drones. Data is also recorded as multispectral or hyper spectral bands by optical sensors carried by drones, encompassing visible, near-infrared, and short-wavelength (Berni *et al.*, 2009; Saari *et al.,* 2011; Shao 2015). Advances in sensor technology have made sensors suitable for remote sensing applications on drones are becoming more and more compact, lightweight, and affordable. Colomina and Molina (2014) and Anderson and Gaston (2013) offer thorough introductions to a variety of drone remote sensing systems.

Real-time operating systems

To help with a real-time operating system (RTOS) provides functions like multitasking, scheduling, inter-task communication, etc. for the implementation of real-time systems (Turci *et al.,* 2017). The essential part required to construct a real-time system is an RTOS. Compilers, linkers, debuggers, and drivers are among the additional software components required to communicate with the hardware of the system: http://www.ni.com. Many applications, including the Internet of Things (IoT), automobiles, RTOSs are used in the development of medical systems, robotics, industrial automation, avionics, and flight control systems (Macher *et al.,* 2015). Since RTOSs prioritize task predictability and efficiency, they include features that allow application tasks to have timing constraints (Stankovic *et al.*, 2004). Small, commercial time-sharing operating systems with real-time extensions and proprietary kernels like Unix and Linux are two types of Real-Time Operating Systems (RTOS). The kernel is the heart and soul of any operating system for a computer, including RTOS. It is in charge of processing, managing tasks, managing memory, and interacting utilizing both application software and hardware. In embedded applications, Small, proprietary kernels are often employed when extremely rapid and highly consistent execution is ensured is required. Small kernel sizes are necessary to meet time constraints, which lowers RTOS overhead. Additionally, kernels need to support multitasking, have a quick context switch, prioritize tasks based on priority, give most primitives maintain a high-resolution real-time clock with a limited execution time (Stankovic*et al.,*2004).

UAV Battery Charging

Jawad *et al.,* 2017 three recommendations for improving flying time: (i) Drones with large battery capacities are possible, but they may add to the weight of the device. (ii) After the drone lands, the batteries can be changed. However, it also makes the swapping system complex and expensive. (iii) The drone's base station is where you can recharge it. Power transfer (WPT) systems, either wired or wireless, can be used to accomplish charging. We then quickly reviewed WPT techniques.

Different WPT Techniques

Junaid *et al.,* 2019 offered a closed-loop, vision-based method for outdoor UAV target detection. The authors created a charging station that increases the UAV's endurance and flight time. Blain (2022) presented a novel mid-air inductive charging mechanism that uses global energy transmission (GET) to charge multiple drones simultaneously without requiring a landing. It is important to note that the majority of studies in the literature considered centralized architecture but concentrated on UAV charge scheduling.

Drone Rules & FAA Regulations

A drone flying across a sunset sky. Federal laws, guidelines, regulations, and policies pertaining to drones can be found on the Federal Aviation Administration Policy Document Library website. Broadly speaking, you ought to be aware of the following fundamental guidelines:

- Cannot soar higher than unless it does so within a 400-foot radius of a structure and not higher than the immediate uppermost limit, 400 feet above the ground level (AGL) of that structure.
- Avoid going faster than 100 miles per hour on the ground.
- Constantly give way to other manned aircraft when flying.
- Avoid flying when there are unfavorable weather conditions, such as strong winds or low visibility, unless there is a minimum of three statute miles of visibility between you and the operator. In the event of cloud cover, the drone needs to be positioned at least 500 feet below and 2,000 feet horizontally from the clouds.
- Steer clear of flying when intoxicated or under the influence of other drugs. Less than 0.04 percent blood alcohol content is required for pilots.
- Never impede law enforcement or emergency response efforts.
- Avoid flying overhead and avoid flying from an aircraft that is in motion.
- Only use the drone from a moving vehicle if there is little to no population in the area below.
- Before taking off, check airspace maps at all times. Apps such as Air-Map, B4UFly, and others can be useful for airspace surveillance. Drones operating in the vicinity of airports must obtain FAA authorization via low-altitude authorization and notification

capability (LAANC) and communicate with tower controllers and airport management.

- Notification of the FAA must be sent within ten calendar days in the event that an operation causes serious harm or property damage exceeding $500.
- Drone pilots are required by the FAA to keep their drone in visual line of sight (VLOS) at all times while in flight, and flying beyond line of sight (BLOS) is forbidden unless a special waiver is obtained.

Applications in forestry

Surveying Forests

Due to Koh and Wich (2012) experimented with using drone remote sensing to survey and map tropical forests in Indonesia due to the high cost of high-resolution satellite remote sensing data, frequent cloud cover, and difficult/expensive ground surveys. A fixed-wing drone that's small (*650 g), light (<$100), and equipped with a 2200 mAh battery and a still/video camera was used in the experiment. This drone could travel *15 km in total during each mission, lasting *25 minutes. The researchers identified flora, surveyed wildlife species using a combination of photographic and video data, and recognized human activities (like logging and burning) using the video footage. Additionally, they put together the drone photos to produce maps of land cover and use with a 5.1 cm spatial resolution. They proposed that local researchers and conservationists in developing tropical regions could save a substantial amount of money, labor, and time by utilizing drone remote sensing. According to Paneque-Galvez *et al.* (2014), these applications are particularly useful for community-based forestry and forest monitoring initiatives in developing nations, Reducing Emissions from Deforestation and Forest Degradation, or REDD, for example. Drone remote sensing has become popular among forest surveyors as a way to improve forest measurements.

Mapping canopy gaps

Small forest gaps are difficult to measure precisely with satellite remote sensing, but they reflect disturbance and impact productivity and diversity in forests (Frolking*et al.,* 2009). In order to accurately identify Getzin *et al.* (2012) acquired 7-cm-resolution, natural-color images for beech-dominated deciduous and deciduous-coniferous mixed forests in Germany, with gap objects as small as 1 m2. The drone, weighing 6 kg and having a wing span of 2 m, could fly for up to 60 minutes at an altitude of 250 m. Pre-programmed flight lines and all images were ortho-rectified depending on a digital terrain model, GPS position, and internal drone orientation. Strong correlations were observed by the researchers between the metrics for forest gap obtained from drone remote sensing and the measurements of biodiversity. According to this study, drone remote sensing can capture extremely high-resolution photos that are useful for classifying forest gaps as trustworthy markers of biodiversity. The drone's ability to operate at low altitudes was essential to the study's successful acquisition of high-resolution images. The digital surface model is useful for calculating the amount of forest canopy, is a significant imaging product.

Precision Forestry and Sustainable Forest Planning Management

In forest planning and Factors such as stand composition, vitality, volume estimation, tree count, and canopy cover are critical to sustainable forest management. Unmanned aircraft have the potential to determine the canopy cover quickly and accurately, enabling quicker decision-making that improves the stand's productivity and quality utilizing a drone that has an L-band synthetic aperture radar (SAR) sensor installed, researchers in 2014 calculated the *Pinustaeda* forests' basal area and biomass volume. The authors came to the conclusion that only L-band or shorter wavelength radar would be useful for measuring these parameters on young stands with lower BA (Basal Area) and lower AGB (Above Ground Biomass), which are similar to stands from their study.

In order to estimate the volume of the wood chips pile, Mokroš *et al.,* 2022 used a commercial, low-cost quad-copter (DJI Phantom 3 Professional) to fly at a 20-meter altitude. Using UAVS does not significantly change the results (10.4% more volume estimated via drone method) and reduces the time required for data collection (12–20 times less), with the benefit of documentation through ortho-mosaic image, the authors concluded after comparing the results with the volume determined by a GNSS (Global Navigation Satellite System) device. Hassaan *et al.,* 2023 employed a commercial quad-copter (DJI Phantom 2) with a 20-minute maximum flight duration to efficiently count trees in urban areas, achieving a 72% accuracy rate in tree identification. Wallace *et al.,* (2014) also successfully completed a paper that involved counting the quantity of trees that can be counted with LiDAR (Light Detection and Ranging) equipment mounted on a UAV.

From a drone remote sensing perspective, Precision agriculture can be applied to fast-growing forest plantations, and one of the main goals is to increase their productivity, particularly in light of the rapidly rising demand for timber. In this area, Felderhof and Gillieson used Using drone remote sensing, a macadamia plantation's tree canopy vitality can be mapped. They discovered strong relationships between the in-situ measurements of nitrogen in the leaves and the spectral radiation of the trees. According to research by Zahawi *et al.,* (2021), the drone-based methodology for monitoring the recovery of forest vegetation in tropical regions is workable even for substantial amounts of data. Lehmann *et al.,* 2017 According to a study, UAVS has the ability to identify the degree of agricultural biguttatus pest infestation in tiny stands of oak forests. The authors employed a business quad-copter equipped with a 200 g payload capacity and an estimated flight time of 30 minutes to capture images with a very high spatial resolution (2 cm) using a low-cost digital CIR camera (Canon IXUS 100 featuring an infrared sensor). Based on five classes, their results showed an overall accuracy of over 82.5% and an estimated 50% time and cost savings for small/medium sized stands over traditional ground-based pest detection workflow. Future research will greatly benefit from unmanned aerial vehicles in areas like mapping and assessing forest disturbances, forest dynamics, and the proportions of different. The benefits of unmanned aircraft technology will lead to a significant increase in mapping and assessment of forest disturbances, as well as the diversity of forest species in stands.

Measuring forest canopy height

An essential component of forest quantification is the forest canopy height, which is typically measured using ground surveys and analog photogrammetric techniques. According to Lefsky *et al.* (2002), lidar technologies have emerged as a new method for estimating canopy height, and traditional photogrammetry in forestry has all but disappeared. Especially with the growing affordability of drone-borne Lidar technologies (Tulldahl and Larsson 2014; Wallace *et al.,* 2014), this is the case. Furthermore, by combining digital photogrammetry and structure-from-motion methods, high-resolution, low-oblique drone-borne optical imagery supports the measurement of forest canopy height (Siebert and Teizer 2014).

Lisein *et al.,* (2013) presented a comparable methodology for a Belgian forest. To obtain NIR images with a spatial resolution of *7.6 cm, they used a small fixed-wing drone with a wingspan of 1 m, a weight of 2 kg, a cruise speed of 80 km/h, a flight height of 100–750 m, and a maximum flight duration of 40 min. The Lidar data acquired from an expensive crewed aircraft showed strong agreement with the measurements of forest canopy height obtained from the low-cost photogrammetric method. Zarco-Tejada *et al.* (2014) used a fixed-wing drone with a 2-meter wingspan and a 63 km/h flying speed to measure the height of trees in 158 hectares of forestland in Spain. The camera was inexpensively mounted on the drone.

A cheap camera was altered to produce 5 cm spatial resolution color infrared images. When compared to values measured on the ground, the tree height values derived from the photos proved to be accurate. In the United States, a study by Dandois and Ellis (2013) used a comparable photogrammetric methodology. Utilizing a consumer-grade camera fixed atop a small rotary-wing drone operating at a low altitude of 130 meters, they were able to obtain overlapping aerial photographs.

Three 625-ha deciduous forests in the state of Maryland made up the study site. They found this method satisfactory for observing 3D canopy phenology at high temporal resolutions. Another compelling argument for foresters to use drone remote sensing in their research is the availability of low-cost yet powerful technologies for multispectral 3D scanning of vegetation. The three experiments mentioned above indicate that the accuracy of this low-cost optical method is comparable to that of more sophisticated and expensive Lidar systems.

Tracking forest wildfires

We are still in the early stages of using remote sensing to support real-time fire-control tactics (Wing *et al.,* 2014). With its high temporal resolution (1-2 days for revisiting), MODIS satellite imagery is frequently used for managing and monitoring forest wildfires. At local scales, however, MODIS's low spatial resolution is inadequate for this task. Crews may be put in danger when crewed aircraft are deployed to monitor forest wildfires in real time.

NASA and the US Forest Service demonstrated the use of a large, fixed-wing drone for forest wildfire management between 2006 and 2010. The drone was used for a full day (Ambrosia *et al.,* 2011; Hinkley and Zajkowski 2011). The drone could carry instruments weighing up to one ton and weighed close to five tons. Using a multispectral scanner that they mounted, the researchers were able to gather image data with 16 bands—from visible to TIR—autonomously. Improved wildfire imagery was produced using the TIR-band data. Near real-time (5–10 min) intelligence was provided by the drone remote sensing missions to help manage forest wildfires. In Portugal and Spain, researchers also tested rotary-wing drones' capacity to identify wildfires in forests (Martinez-de Dios *et al.,* 2011; Merino *et al.,* 2012). Rotating-wing drones have demonstrated the ability to efficiently gather real-time data on forest wildfires, according to a series of experiments. More specifically, complementary views of wildfires could be obtained and larger areas could be measured by using multiple drones at the same time, either autonomous or remotely controlled. Drones operating at medium and high altitudes are better suited for flying over wildfire areas.

Supporting intensive forest management

According to Arano and Munn (2006) and Bai *et al.* (2015), intensive forest management is a useful strategy for boosting forest productivity and satisfying the growing demand for timber. Drone remote sensing can help manage rapidly expanding forest plantations in a manner akin to precision agriculture (Wang *et al.,* 2014). Applying fertilizer at the appropriate time and location is a common exercise. Felderhof and Gillieson (2011) mapped the health of the tree canopy in a macadamia plantation using NIR imagery obtained through drone remote sensing. They discovered a strong relationship between leaf nitrogen levels ascertained by field sampling and spectral radiometry. This strategy increased economic returns and reduced the cost of intensive forest management by utilizing drones.

To maximize the productivity of forests, controlling forest density is an essential traditional forestry practice. Remote sensing from drones can be used to get landscape-level data on the density of forests from wall to wall. To improve the quality and value of timber, forest plantations must be pruned. In order to gather three-return Lidar data of a four-year-old Eucalyptus stand situated in Tasmania, Australia, Wallace *et al*. (2014) conducted an experiment. The scanning platform was a drone with rotor wings that could fly slowly and at a low altitude of 40 meters. They were able to produce point clouds with high densities (145 and 220 pulses/m2). Data from Lidar was gathered both prior to and following pruning. The data was automatically segmented into individual tree crowns, and base height and crown volume were calculated using the geometry of the point cloud. The outcomes demonstrated that the unpruned and pruned stems had significantly different canopy properties, suggesting that the drone-based Lidar system could successfully differentiate between pruning treatments. There were moderate correlations between field-measured crown base heights and Lidar-derived crown base heights at the individual tree level. Laser scanners are becoming more and more lightweight, allowing them to be installed on smaller drones (Tulldahl and Larsson 2014), increasing the effectiveness and affordability of their forestry applications.

Future Research Directions

We address some potential future directions for UAV research as follows, based on the literature analysis:

Machine Learning and Deep Learning Techniques

In a variety of UAV-related applications, including resource allocation, obstacle avoidance, battery scheduling, trajectory planning, and tracking, machine learning and deep learning techniques show great promise. New machine learning tools and increased onboard computing capacity will aid in the creation of innovative UAV models that are smaller, lighter, and smarter so they can carry out any task without running the risk of colliding. UAVs can autonomously change their motion, direction, and location to benefit ground users by using these tools. Furthermore, precise data availability can help UAVs with tasks like trajectory planning, smart control, and vision. A UAV equipped with various cameras can take a variety of pictures that can be processed further. To locate a desired path, UAV planning can be done, including trajectory, navigation, and manipulation. In a similar vein, load sharing and ground user movement can be acquired for UAV trajectory planning. While traditional machine learning techniques have been integrated into unmanned aerial vehicles (UAVs), deep learning techniques have not been investigated because of restricted processing power and resources. Therefore, the research community should look into effective and low-power deep learning techniques for UAVs, particularly for SAR operations.

Energy Harvesting Techniques

To fully utilize UAVs for long-duration missions, new materials for their batteries and innovative approaches to energy harvesting must be explored. Future issues include battery weight and charging time. Finding lightweight batteries that can greatly extend the flight time and support longer distances for UAVs is therefore necessary. Future research should focus on effective ways to regulate the battery power consumption of LoT terminals in UAVs.

Sensing, Navigation and Localization Algorithms

More investigation is required into sensing, navigation, and localization. Weak GPS systems that are used to determine location are the cause of these issues, which can lead to difficulties with precise and timely parcel delivery. Localization is one of these that is crucial to the safe operation of UAVs. UAVs are known for their high and unpredictable mobility, which makes accurate localization challenging in a hurry. The three-dimensional mobility of UAVs in an environment that is highly dynamic and obstacle-based limits their location accuracy. GPS is typically used to track location, but because of the dense deployment of UAVs, it can cause unnecessary delays and costs. Thus, for effective UAV location, the integration of localization systems and inexpensive sensors needs to be studied.

Offloading Algorithms

It is best to perform several tasks at once when performing different operations. Multi-UAVs are becoming more and more in demand for these kinds of jobs. These jobs are split up among the deployed UAVs so that each one receives the appropriate attention when needed. High mobility scenarios, time- and commute-sensitive UAV applications, and cost-effective task offloading are all important considerations. To lower the overall energy used for completing predefined tasks, researchers should develop new task offloading algorithms.

Mobility Models

Networks of UAVs are susceptible to high mobility. Frequent changes in topology can harm UAV cooperation and communication. Numerous mobility models have been put forth to address mobility-related problems, but they fall short when it comes to addressing communication problems. These models need to be created with the needs of the network in mind. When UAVs move slowly, they greatly reduce network coverage, which causes higher network latency. However, in emergency situations, minimally latency mobility models are needed. Moreover, persistent network connectivity results in a decline in network efficiency. Therefore, in order to address mobility challenges, innovative mobility models should be created for specific applications and environments.

Aerial Blockchain

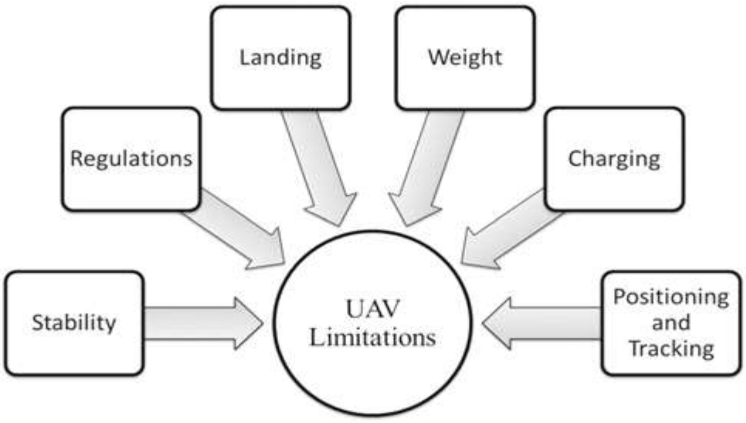
For blockchain-based UAV systems, block chain technology is expected to bring in a new era of flexible and safe privacy protection as a decentralized solution. Aerial blockchain can safeguard the integrity of data collected by UAVs and stop privacy breaches in UAV communications. Additionally, communication services over the UAV network with dynamic, flexible, and on-the-fly decision capabilities may be provided by a block-chain enabled UAV softwarization. Although there have been several attempts to investigate blockchain technology in UAV networks, block-chain-enabled softwarization for UAV networks has not yet been explored by researchers.

Novel Antenna Designs Techniques

To ensure high data rate communication, UAVs should be equipped with innovative antenna designs. It is recommended that UAVs traveling at greater speeds use small, aerodynamic antennas. Similar to this, tiny UAVs can overcome energy and space constraints by utilizing directional antennas. Furthermore, because they save space, tilted-beam circularly polarized antennas are widely used. It is anticipated that performance will be improved in terms of return losses, axial ratio, and radiation pattern by using such antennas. Network lifetime can be increased by utilizing backscatter antennas and WPT techniques. Multi-adaptive antenna integration can facilitate communication in ultra-mobile unmanned aerial vehicles.

Advantages of UAV’s

Unmanned Aerial Vehicles (UAVs) can take pictures in hazardous environments. They can fly in light rain and beneath clouds. They are not constrained by physiological factors that would affect light aircraft pilots who are humans. A UAV called a field helicopter is equipped with multispectral sensors for crop and soil analysis. Compared to satellite imagery, it can fly and take pictures in over 70% of weather scenarios. The use of UAVs in a variety of applications has many advantages. On the other hand, it is contingent upon the aircraft, sensor kinds, mission goals, and their platforms. Before putting any UAV applications into practice, all of these factors must be taken into account. UAVs have many benefits, including the ability to fly below clouds, the ability to acquire data quickly and in real-time, the ability to use them in high-risk situations at low altitude, the lack of physiological restrictions and financial burdens, the availability of imagery "on-demand," affordability, geo-referenced images that allow for direct connections with GIS packages, low maintenance requirements, and safety.



Limitations

The weight and size of the low-cost UAV's sensors are its limitations. Small or medium amateur formats are typically less accurate and less stable. Because of their less potent engines, low-cost UAVs are limited in their ability to reach certain heights. When using UAVs, there are a few issues to take into account. These include the path-planning system's lack of a professional pilot, the high-speed, ultra-low conditions, the data downloading function during real-time application, the payload's size and composition to prevent bottlenecks, and the software for the system's automatic processing.

CONCLUSION

Drones are unmanned aircrafts that are remarkably small, consume very little energy, and are inexpensive to use all without endangering human life. Drone applications in forestry are still in their experimental stages, but there is a lot of promise for the future. The use of UAVS in forestry will be greatly enhanced by the growing accessibility of LiDAR and infrared sensors in terms of price and size, as well as data combining techniques. Newer models of UAVS will always be developing, with longer flight times and better sensors. Future research will cover a wide range of forestry topics, including species detection, forest dynamics, evaluating forest disturbances, and more. All of these studies will need to be implemented quickly to address the variety of scenarios that arise in the sustainable management of forests.

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