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UAV Route Survey Planning and Quality Control for Height Measurement

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Abstract

Unmanned Aerial Vehicles (UAVs) are versatile tools for route surveying across industries. This document explores their significance, methodologies, challenges, and best practices. It covers UAV technology, applications, advantages over traditional methods, and flight planning considerations using GIS data. Factors like altitude, speed, and camera settings are discussed, along with height measurement techniques such as photogrammetry and LiDAR. Challenges in obtaining accurate height data and quality control measures are addressed. Case studies and best practices from successful projects are highlighted, emphasizing regulatory compliance and safety protocols. This document offers a comprehensive guide for optimizing UAV route surveying workflows and achieving effective data collection and analysis.

UAV (Unmanned Aerial Vehicle), Route survey planning, Quality control

Height measurement, surveying methodologies

Introduction:

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have revolutionized various industries, including surveying and mapping. One crucial application of UAVs is route surveying, where they are employed to map terrain and infrastructure along specific routes with high precision. In this seminar, we will explore the planning process and quality control measures for UAV route surveys, with a focus on ensuring accurate height measurements.

UAV route surveying, also known as drone-based route surveying, involves the utilization of Unmanned Aerial Vehicles (UAVs) or drones to execute surveying tasks along specified routes or corridors, such as highways, railways, power lines, pipelines, or other linear infrastructure (Cao et al., 2020). The significance of UAV route surveying lies in its capacity to swiftly and cost-effectively provide precise, high-resolution spatial data (Shamsudin et al., 2020). Drones equipped with various sensors, including cameras, LiDAR (Light Detection and Ranging), or GNSS (Global Navigation Satellite System) receivers, capture aerial imagery, terrain data, and other geospatial information along predefined routes. Subsequently, the collected data is processed and analyzed to generate detailed maps, 3D models, and other valuable outputs for planning, design, construction, and maintenance purposes (Mishra et al., 2019).

One of the primary advantages of UAV route surveying is the significant time and cost savings it offers compared to traditional surveying methods. Drones can efficiently cover large areas, reducing the time required for data acquisition (Wang et al., 2020). Moreover, their ability to access remote or hazardous areas, which may be challenging or unsafe for ground-based surveying teams, enables comprehensive data collection in diverse environments (Al-Rawabdeh et al., 2020). Furthermore, advancements in sensor technology and data processing algorithms facilitate the attainment of high levels of accuracy in spatial data capture, essential for engineering projects necessitating precise measurements and analysis (Wang et al., 2016).

Additionally, UAV route surveying exhibits adaptability to various project requirements, allowing customization to specific needs. Drones can capture different types of data and operate at different altitudes and speeds, catering to distinct project objectives (Sharma et al., 2020). Moreover, UAVs equipped with live video streaming capabilities enable real-time monitoring of project sites, facilitating prompt decision-making and issue resolution (Abdullah et al., 2020). Furthermore, compared to traditional surveying methods involving manned aircraft or ground-based equipment, UAV route surveying boasts a lower environmental footprint, as drones consume less energy and produce fewer emissions, aligning with sustainable data collection practices (Colomina & Molina, 2014).

Applications in infrastructure development, environmental monitoring, and precision agriculture.

UAV route surveying boasts a multifaceted range of applications spanning infrastructure development, environmental monitoring, and precision agriculture.

In infrastructure, drones play a pivotal role in evaluating road conditions, planning new construction projects, and monitoring ongoing developments (Rango et al., 2012). With their ability to capture high-resolution imagery and LiDAR data, UAVs facilitate the creation of detailed terrain models and aid in identifying potential obstacles, thus optimizing road alignments and enhancing overall project efficiency (Chen et al., 2017). Similarly, in railway infrastructure, drones are utilized for inspecting tracks, bridges, and other critical components, enabling authorities to detect maintenance issues early and ensure the safety and integrity of the railway network (Ni et al., 2019).

Utility companies harness the power of UAV route surveying to conduct comprehensive inspections of power lines, pipelines, and other linear infrastructure assets (Suzuki et al., 2019). Drones equipped with advanced sensors enable utilities to identify vegetation encroachment, detect leaks, and assess infrastructure conditions with precision, even in remote or inaccessible areas (Rosser et al., 2019). This proactive approach to maintenance and monitoring helps utilities enhance operational efficiency, minimize downtime, and ensure the reliability and resilience of essential infrastructure networks.

Additionally, in environmental monitoring, drones serve as invaluable tools for natural resource management, facilitating forest monitoring, biodiversity assessment, and the detection of illegal activities such as logging or mining (Hamunyela et al., 2019). By providing real-time data and insights, UAV route surveying aids environmental agencies in preserving ecosystems, combating deforestation, and safeguarding natural habitats for future generations.

In the realm of precision agriculture, UAVs revolutionize farming practices by offering unprecedented capabilities for crop monitoring, pest detection, and resource optimization (Zhang et al., 2020). Equipped with multispectral and thermal sensors, drones generate high-resolution maps of agricultural fields, enabling farmers to analyze soil variability, optimize planting patterns, and implement precision farming techniques (Kussul et al., 2017). Moreover, UAV route surveying enables livestock monitoring, allowing ranchers to track animal movements, evaluate pasture conditions, and optimize grazing strategies (Moeckel et al., 2017). By leveraging the insights provided by drones, farmers can make data-driven decisions that enhance crop productivity, improve resource efficiency, and promote sustainable agricultural practices

Advantages over traditional surveying methods.

UAV route surveying presents several advantages over conventional surveying techniques, making it a preferred option for various applications (O'Sullivan & Unwin, 2014). Firstly, it offers significant cost savings, as drones require fewer personnel to operate, incur lower equipment expenses, and complete surveys in less time compared to traditional methods (Foody, 2002). This cost-effectiveness is particularly advantageous for large-scale projects where efficiency and budget constraints are critical considerations. Additionally, drones excel in rapid data acquisition, covering large areas efficiently and providing high-quality spatial data in a fraction of the time required by ground-based or manned aircraft surveys (Hardin & Jensen, 2019). Their ability to access remote, hazardous, or otherwise inaccessible areas further enhances their utility, enabling comprehensive data collection in diverse terrain conditions without compromising safety. Flexibility is another key advantage, as operators can easily adjust flight paths, altitudes, and camera settings to meet specific project requirements, ensuring tailored data collection and optimized survey outcomes.

Furthermore, drones offer exceptional versatility in flight planning and data collection parameters, allowing for customized approaches tailored to the unique needs of each project (Berni et al., 2009). Their high-resolution imagery capabilities facilitate precise mapping and analysis of terrain features, infrastructure, and environmental conditions, enhancing the accuracy and relevance of surveying data compared to traditional methods. Real-time monitoring capabilities enable immediate feedback to surveyors and project managers, facilitating on-the-fly adjustments to flight paths and data collection parameters, thereby improving overall efficiency and productivity. Moreover, UAV route surveying demonstrates a lower environmental footprint, consuming less energy, producing fewer emissions, and causing minimal disturbance to the surrounding environment (Hardin & Jensen, 2019). This sustainability aspect underscores the role of drones as an eco-friendly option for data collection in surveying applications, aligning with modern environmental standards and promoting responsible practices in the field of geospatial technology.

Flight Planning for Route Surveys

Flight planning is a pivotal stage in UAV route surveys, serving as the foundation for mission success and data integrity. The process encompasses several key steps to ensure efficient and effective data collection along the designated route. Initially, selecting the route for surveying involves considering factors such as route length, accessibility, airspace regulations, and specific survey objectives. Pre-flight analysis utilizing GIS data and aerial imagery aids in identifying potential obstacles, hazards, and points of interest along the route, guiding decisions on flight path and altitude.

Mission planning software or UAV flight planning apps are indispensable tools for defining mission parameters, including route coordinates, waypoints, altitude, speed, and camera settings. Waypoints are strategically positioned along the route to ensure comprehensive coverage and uniform image capture, taking into account terrain variations and camera field of view. Determining the appropriate UAV altitude is crucial, balancing ground sampling distance requirements, sensor specifications, and survey accuracy considerations. Additionally, configuring camera settings optimizes image quality and exposure consistency, while incorporating obstacle avoidance algorithms or manual intervention mechanisms enhances flight safety.

Consideration of weather conditions, compliance with regulations, implementation of safety protocols, and post-flight evaluation further contribute to a successful flight planning process. Adhering to these steps ensures meticulous planning and execution, facilitating high-quality data acquisition and meaningful insights from UAV route surveys.

Route selection and mission planning.

Embarking on UAV surveys necessitates meticulous route selection and mission planning to achieve successful outcomes and obtain high-quality data. The first step involves defining the survey objectives, articulating the desired data types, spatial resolutions, and target features along the route. This clarity lays the groundwork for subsequent planning stages and ensures that the survey aligns with project goals.

Next, a comprehensive assessment of route characteristics is essential to gauge factors such as length, terrain complexity, and proximity to obstacles or hazards. By understanding these attributes, surveyors can identify routes conducive to UAV operations while minimizing risks. Accessibility and safety are paramount considerations, requiring confirmation that selected routes are accessible for UAV deployment and comply with airspace regulations. Additionally, logistical factors such as launch and recovery sites and landowner permissions must be addressed to facilitate smooth survey operations.

Optimizing flight parameters is crucial for efficient data collection. This entails determining the optimal flight altitude and speed considering ground sampling distance, sensor capabilities, and survey accuracy requirements. Weather conditions must also be closely monitored to ensure safe and effective flights. By staying abreast of factors such as wind speed, precipitation, and visibility, surveyors can avoid adverse conditions that could compromise UAV performance or data quality. Additionally, contingency plans should be developed to address unforeseen events or system failures, mitigating risks and ensuring mission success. Through meticulous planning and attention to detail, UAV surveys can yield valuable insights and contribute to informed decision-making in various fields.

GIS data for pre-flight analysis and route optimization.

Leveraging Geographic Information System (GIS) data is integral for effective pre-flight analysis and route optimization in UAV surveys (Longley et al., 2015). Accessing diverse GIS datasets pertinent to the survey area provides crucial information for route planning, including topographic maps, land cover data, elevation models, cadastral data, and infrastructure layers such as roads and power lines. Integrating these GIS layers into specialized software platforms like ArcGIS or QGIS facilitates comprehensive analysis, ensuring uniformity in coordinate systems and projections for accurate spatial planning.

Performing terrain analysis using elevation models enables the identification of elevation variations, slopes, and rugged terrain features along the survey route (Longley et al., 2015). This information aids in assessing the feasibility of UAV operations and identifying potential obstacles or hazards. Analyzing land cover data helps understand vegetation density, canopy height, and land use patterns along the route, crucial for evaluating the impact of vegetation on UAV flights and sensor performance. Moreover, examining infrastructure layers allows for the identification of existing infrastructure features and potential conflicts with UAV flight paths, ensuring safe and efficient survey operations. Conducting visibility analysis enables the evaluation of line-of-sight conditions along the route, considering terrain obstructions and vegetation cover, guiding decision-making for flight planning and ensuring data collection integrity.

Optimization Techniques

Employing GIS-based optimization techniques in UAV route survey planning enhances efficiency and data quality (Bolstad, 2016). Utilizing algorithms like least-cost path analysis, network analysis, and spatial clustering allows for the identification of optimal flight paths and waypoints based on factors such as distance, terrain ruggedness, and obstacle avoidance (O'Sullivan & Unwin, 2014). This approach facilitates the creation of flight routes that minimize travel time and maximize coverage while avoiding potential hazards.

Additionally, conducting risk assessments using GIS data analysis helps identify safety hazards, regulatory constraints, and environmental sensitivities along the survey route (Longley et al., 2015). By evaluating the level of risk associated with each segment of the route, mitigation measures can be prioritized to ensure safe and compliant UAV operations. Iterating the route planning process based on feedback from GIS analysis, stakeholder input, and field reconnaissance enables continuous refinement of flight paths, waypoints, and data collection parameters, ultimately optimizing survey efficiency and data quality.

Factors influencing flight parameters

Determining optimal flight parameters for UAV surveys involves considering various factors such as altitude, speed, and camera settings (Hardin & Jensen, 2019). These parameters are tailored to meet specific mission requirements and the characteristics of the survey area. For instance, the type of data needed, whether it's aerial imagery, LiDAR point clouds, or thermal imagery, guides the selection of sensor payloads and subsequently influences flight altitude, speed, and camera configurations (Berni et al., 2009). Additionally, factors like desired spatial resolution and ground sampling distance (GSD) dictate flight altitudes, with higher resolutions demanding lower altitudes for detailed imagery and vice versa.

Moreover, considerations such as the size and shape of the survey area, terrain ruggedness, and presence of obstacles influence flight parameters (McGonigal & Nelson, 2019). Larger areas may necessitate higher altitudes and faster speeds for efficient coverage, while rough terrain or obstacles like buildings and trees may require adjustments to flight paths and altitudes to ensure safety and data accuracy. Weather conditions, regulatory requirements, and data processing considerations further shape flight planning, with factors like wind speed, airspace regulations, and photogrammetry workflows impacting parameter selections (Colomina & Molina, 2014). Overall, balancing mission objectives, operational constraints, and environmental factors is essential in determining flight parameters that optimize data quality and survey efficiency in UAV operations.

Height Measurement Techniques

Height measurement techniques in land surveying are critical for accurately assessing elevations and terrain features essential for various land development and construction projects (Bolstad, 2016). Surveying instruments like total stations and levels, equipped with electronic distance measurement technology, ensure precise vertical measurements (O'Sullivan & Unwin, 2014). Additionally, Global Navigation Satellite System (GNSS) receivers provide elevation data by calculating heights above reference geoid models, enhancing accuracy through techniques like Differential GNSS (DGPS) (Longley et al., 2015). Moreover, laser scanning (LiDAR) technology offers detailed height measurements by emitting laser pulses to determine distances to objects and surfaces, enabling precise elevation mapping in land surveying (Hardin & Jensen, 2019).

Photogrammetry, another valuable technique, involves extracting three-dimensional information from overlapping images, generating point clouds and digital surface models for height measurement (Colomina & Molina, 2014). These methods play a pivotal role in land surveying, enabling surveyors to gather accurate elevation data crucial for land development, infrastructure planning, and construction projects (McGonigal & Nelson, 2019). With advancements in technology, height measurement techniques continue to evolve, providing surveyors with increasingly precise tools for comprehensive terrain analysis and mapping.

Height measurement using UAVs, (photogrammetry and LiDAR).

Height measurement using Unmanned Aerial Vehicles (UAVs) offers versatility through techniques like photogrammetry and LiDAR (Light Detection and Ranging), each with distinct advantages and considerations (Berni et al., 2009). Photogrammetry relies on overlapping aerial images captured by UAV-mounted cameras to reconstruct 3D models of the terrain and objects, enabling accurate measurement of ground elevation and various features (Anderson & Gaston, 2013). While cost-effective and suitable for capturing detailed surface textures, photogrammetry's accuracy may be compromised in densely vegetated areas or regions lacking texture (Colomina & Molina, 2014). Conversely, LiDAR utilizes laser pulses emitted from UAV-mounted sensors to generate highly accurate 3D point clouds of the terrain and objects, providing precise elevation data even in complex terrain or dense vegetation (Hardin & Jensen, 2019). However, LiDAR incurs higher costs and requires specialized expertise for data processing and analysis, despite its capability to penetrate vegetation canopy and capture detailed 3D information.

In summary, both photogrammetry and LiDAR techniques offer valuable solutions for height measurement using UAVs, catering to various surveying needs and terrain characteristics. The choice between these methods depends on factors such as project requirements, budget constraints, and the level of detail and accuracy desired. With advancements in technology and ongoing research, height measurement using UAVs continues to evolve, presenting opportunities for improved data collection and analysis in land surveying and related fields.

Challenges and limitations in achieving accurate height data.

Terrain irregularities, such as steep slopes, cliffs, valleys, and undulations, pose challenges for height measurements using UAV-based sensors (Hardin & Jensen, 2019). In rugged terrain, UAVs may struggle to capture accurate elevation data, leading to errors in height measurements (Colomina & Molina, 2014). Similarly, dense vegetation canopy can obstruct LiDAR pulses and obscure ground features in photogrammetry, resulting in inaccuracies in height measurements (Berni et al., 2009).

The resolution and accuracy of UAV-mounted sensors, including cameras and LiDAR scanners, significantly impact the quality of height data (Hardin & Jensen, 2019). Lower-resolution sensors may produce less detailed elevation models, while errors in sensor calibration or georeferencing can introduce distortions in height measurements (Foody, 2002). Proper calibration, georeferencing, and data processing techniques are crucial to ensure accurate results and minimize errors (Hardin & Jensen, 2019).

Additionally, factors such as atmospheric conditions, flight planning, ground control points, and data integration must be carefully considered to obtain reliable height measurements (Colomina & Molina, 2014). Adverse weather conditions can affect LiDAR or ultrasonic height measurements and impact UAV flight stability (Berni et al., 2009). Proper flight planning, including optimizing flight parameters and sensor settings, is essential for achieving accurate data collection (Foody, 2002). Integration of data from multiple sources requires attention to data compatibility, alignment, and fusion techniques to avoid discrepancies in height measurements (Colomina & Molina, 2014). Regulatory restrictions and airspace limitations may also affect UAV flights, limiting access to certain areas or imposing constraints on flight altitude and operating conditions (Hardin & Jensen, 2019)

Integration of ground control points (GCPs) for height accuracy enhancement.

Integration of ground control points (GCPs) is pivotal in enhancing height accuracy in UAV-based surveys, particularly in photogrammetry and LiDAR applications (Hardin & Jensen, 2019). GCPs serve as reference points with accurately known coordinates, strategically distributed across the survey area (Colomina & Molina, 2014). Survey-grade

GNSS receivers or RTK GPS systems are employed to achieve centimeter-level accuracy in GCP coordinates, which are then marked on the ground using durable markers (Berni et al., 2009). During UAV data processing, GCPs are identified in the aerial imagery and matched to their known ground-truth coordinates (Foody, 2002). These points are instrumental in georeferencing UAV-derived orthomosaics, point clouds, and elevation models, allowing for precise elevation measurements (Colomina & Molina, 2014). Discrepancies between observed and ground-truth elevations of GCPs are used to compute correction factors, thereby improving overall height accuracy (Hardin & Jensen, 2019).

Quality control measures, including pre-flight planning, equipment checks, data processing rigor, and validation against ground truth references, are essential to ensure the accuracy and reliability of height data obtained through UAV surveys (Hardin & Jensen, 2019). Thorough pre-flight planning involves defining survey objectives, selecting appropriate UAV platforms, and determining flight parameters, including GCP placement (Colomina & Molina, 2014). Pre-flight checks ensure the readiness of UAV equipment, while monitoring during flights ensures stable operation and adherence to flight paths (Berni et al., 2009). Capturing high-quality data requires attention to camera settings, sensor calibration, and environmental conditions (Foody, 2002). Rigorous data processing is vital for generating accurate elevation models, with quality control checks identifying and correcting errors (Hardin & Jensen, 2019).

Validation against ground truth references quantifies the vertical accuracy of UAV-derived height data, providing an objective assessment of data quality (Berni et al., 2009). Comprehensive record-keeping and reporting of quality control results communicate the reliability and confidence level of height data to stakeholders, ensuring traceability and reproducibility in UAV surveying projects (Foody, 2002). By integrating GCPs into UAV surveys and incorporating their known ground-truth coordinates, height accuracy can be significantly enhanced, allowing for more reliable and precise elevation data for various applications, including mapping, topographic surveying, and terrain modeling (Colomina & Molina, 2014).

Quality control in UAV route surveys.

Quality control serves as a cornerstone in UAV route surveys, ensuring that the collected data accurately represent the surveyed route and its features (Hardin & Jensen, 2019). By verifying alignment, dimensions, and attributes of infrastructure elements like roads and paths, quality control measures confirm the fidelity of the data (Colomina & Molina, 2014). Precise georeferencing, facilitated by accurately surveyed ground control points (GCPs), further enhances the reliability of the data, aligning it seamlessly with geographic coordinates (Berni et al., 2009).

In surveys involving elevation data, such as road gradients or bridge clearances, quality control becomes paramount for ensuring height measurement accuracy (Foody, 2002). This accuracy is vital for safety and engineering purposes, as errors in height data could lead to design flaws or safety hazards (Colomina & Molina, 2014). Moreover, consistency across data collection methods, sensor calibration, and processing workflows is crucial for producing dependable results (Hardin & Jensen, 2019). Quality control measures identify and rectify inconsistencies or errors that may arise during various stages of the survey process, bolstering the reliability of the entire dataset (Berni et al., 2009).

Beyond ensuring accuracy and reliability, quality control in UAV route surveys helps maintain adherence to industry standards, regulations, and project requirements (Hardin & Jensen, 2019). High-quality data derived from rigorous quality control instills confidence in decision-making processes for infrastructure planning, maintenance, and development (Foody, 2002). Early investment in quality control measures not only prevents errors and rework but also mitigates risks associated with data inaccuracies, ultimately leading to cost savings and smoother project execution (Berni et al., 2009). By delivering reliable survey data that meets or exceeds client expectations, quality control measures foster customer satisfaction and trust in the surveying services provided.

Pre-flight Equipment Calibration and Readiness Check

Performing thorough pre-flight checks is crucial to ensure the safe and successful operation of a UAV mission (Hardin & Jensen, 2019). This checklist covers various aspects of the UAV system, including the airframe, propellers, battery, remote controller, sensors, payloads, camera settings, GNSS receiver, ground control points, flight planning parameters, weather conditions, emergency procedures, and documentation (Berni et al., 2009). By systematically inspecting each component and verifying key parameters such as connectivity, functionality, and alignment, operators can mitigate potential risks and ensure that the UAV is ready for flight (Colomina & Molina, 2014). Additionally, documenting pre-flight checks and any identified issues facilitates accountability, traceability, and compliance with regulatory requirements, contributing to the overall safety and effectiveness of the mission (Foody, 2002).

In-flight Height Accuracy Monitoring and Adjustments.

In-flight monitoring and adjustments play a critical role in ensuring the accuracy of height data collected during UAV-based surveys (Hardin & Jensen, 2019). Real-time altitude monitoring, utilizing telemetry data from onboard altimeters or barometers, allows operators to track the UAV's altitude relative to the planned flight path (Chen & Li, 2019). Continuous assessment of Ground Control Point (GCP) visibility ensures that markers remain identifiable in aerial imagery, prompting adjustments to flight altitude or orientation if needed to maintain clear visibility (Berni et al., 2009). Optimization of camera settings in real-time helps enhance image quality, ensuring sharp and clear captures for accurate photogrammetric processing (Foody, 2002). Stable flight characteristics are essential to minimize variations in data quality, necessitating vigilance in maintaining steady altitude, speed, and orientation while avoiding abrupt changes in trajectory (Colomina & Molina, 2014). Monitoring GPS/GNSS signal strength ensures reliable georeferencing throughout the flight, while awareness of environmental conditions allows for adjustments to flight parameters in response to factors like wind speed and temperature (Hardin & Jensen, 2019). Comprehensive data logging and real-time feedback provide insights for dynamic adjustments to flight parameters, supported by effective communication and collaboration between UAV operators, mission planners, and ground personnel (Berni et al., 2009).

Data Processing and Analysis

Data import and organization are the initial steps in processing UAV-collected data, involving the importation of raw data such as aerial imagery, LiDAR point clouds, GNSS/IMU data, and ground control point (GCP) coordinates, followed by structuring the data into organized formats for efficient processing (Hardin & Jensen, 2019). Georeferencing and coordinate transformation ensure alignment with the Earth's surface coordinate system, facilitating subsequent analysis and integration with existing spatial datasets (Colomina & Molina, 2014). Image processing techniques such as photogrammetry and LiDAR point cloud processing generate orthomosaics, digital surface models (DSMs), and digital terrain models (DTMs), while feature extraction and classification identify and categorize terrain features (Berni et al., 2009). Height data analysis involves deriving elevation metrics and identifying anomalies for further investigation (Foody, 2002). Data integration and fusion combine UAV-derived data with existing GIS datasets for comprehensive analysis and visualization, followed by quality control checks and validation against ground truth measurements (Hardin & Jensen, 2019). Visualization tools facilitate interpretation, and quantitative analysis aids in understanding spatial patterns, culminating in reports and presentations summarizing survey results and recommendations (Berni et al., 2009).

Post-flight processing workflows for generating height models and orthomosaics encompass several steps, beginning with data transfer and backup to ensure data integrity (Hardin & Jensen, 2019). Data pre-processing involves cleaning and organizing raw data, followed by georeferencing and ground control point adjustment to align aerial imagery with the Earth's surface coordinate system (Colomina & Molina, 2014). Image stitching and orthorectification correct geometric distortions, while DSM and DTM generation produce elevation models for terrain analysis (Hardin & Jensen, 2019). Quality control checks validate the accuracy and reliability of generated height models and orthomosaics, ensuring alignment with surveyed areas (Foody, 2002). Visualization and analysis tools facilitate exploration of terrain features, and output generation produces final products such as digital elevation models (DEMs) and contour maps (Berni et al., 2009). Software tools such as GIS, photogrammetry, and remote sensing software, among others, support data processing, analysis, visualization, and reporting, enabling users to derive valuable insights for various applications (Hardin & Jensen, 2019)

Assessing the quality of height data derived from UAV surveys involves a systematic approach that includes visual inspection, comparison with ground truth data, accuracy assessment metrics, error propagation analysis, GCP validation, sensor calibration, smoothing and filtering, iterative refinement, and documentation (Hardin & Jensen, 2019). Visual inspection and comparison with ground truth data identify discrepancies, while accuracy assessment metrics quantify differences between UAV-derived elevation values and reference data (Foody, 2002). Error propagation analysis identifies sources of error, and GCP validation ensures accuracy in georeferencing (Colomina & Molina, 2014). Sensor calibration and post-processing adjustments refine data alignment and accuracy, while smoothing and filtering techniques remove noise and artifacts (Berni et al., 2009). Iterative refinement based on feedback and documentation ensures transparency and accountability in data quality management, culminating in quality assessment reports summarizing accuracy and reliability, along with recommendations for improvement (Hardin & Jensen, 2019)

Infrastructure Inspection and Monitoring

The utilization of UAV route survey projects spans across diverse sectors, each benefiting from the efficiency, accuracy, and safety offered by aerial data collection and analysis (Hardin & Jensen, 2019). In railway infrastructure inspection, companies like BNSF Railway leverage UAVs equipped with LiDAR sensors to efficiently monitor and maintain rail networks (Chen & Li, 2019). Energy companies such as Shell Oil utilize UAVs for pipeline inspections, detecting leaks and structural issues with thermal imaging cameras (Berni et al., 2009). Conservation efforts benefit from UAV technology as organizations like the World Wildlife Fund monitor wildlife populations and habitat changes, aiding in conservation initiatives and anti-poaching efforts (Colomina & Molina, 2014). Agriculture sees advancements through precision farming techniques enabled by UAVs, with companies like DJI providing solutions for crop monitoring and management (Hardin & Jensen, 2019). Construction firms like Skanska use UAVs for monitoring construction progress and site surveys, while emergency response agencies deploy UAVs for disaster assessment and coordination during natural disasters (McGonigal & Nelson, 2019). Other sectors, including mining, utility infrastructure inspection, urban planning, archaeology, and search and rescue operations, also rely on UAV route survey projects to improve operations and decision-making processes (Berni et al., 2009). Overall, UAV technology plays a crucial role in enhancing surveying, monitoring, and management activities across various industries, leading to more informed decision-making and resource management (Hardin & Jensen, 2019).

Case Studies and Best Practices:

The railway company set out to improve track inspection efficiency and accuracy while minimizing disruptions to train schedules (Chen & Li, 2019). To achieve this, they deployed UAVs equipped with LiDAR sensors for aerial surveys of railway tracks, bridges, and infrastructure (Hardin & Jensen, 2019). This adoption led to substantial time and cost savings compared to traditional manual inspections, with LiDAR data offering detailed 3D models facilitating precise detection of defects, vegetation encroachment, and structural abnormalities along the railway corridor (Berni et al., 2009). Implementing regular UAV-based inspections enabled early identification of maintenance issues, reducing the risk of track failures and service disruptions (Rango et al., 2009). Furthermore, integrating UAV data with asset management systems facilitated prioritization of maintenance tasks and resource allocation, ensuring timely repairs and upkeep (McGonigal & Nelson, 2019). Collaboration with regulatory agencies ensured compliance with safety standards and regulations, ensuring successful implementation of UAV-based inspection programs while maintaining safety and regulatory adherence (Chen & Li, 2019).

The farming cooperative aimed to enhance crop management practices and boost yield outcomes through data-driven strategies (Hardin & Jensen, 2019). To achieve this, they employed UAVs equipped with multispectral cameras to capture aerial imagery of farmland, assessing crop health and nutrient levels (Berni et al., 2009). This approach yielded significant results as the cooperative identified areas of stress, nutrient deficiencies, and pest infestations in their fields through UAV-derived data analysis (Colomina & Molina, 2014). This insight enabled targeted interventions like precision irrigation, fertilizer application, and pest control, ultimately leading to improved crop health and increased yields (Hardin & Jensen, 2019). Emphasizing regular UAV-based monitoring for timely interventions and aligning UAV data with precision agriculture software platforms were identified as best practices, facilitating efficient data analysis and decision-making for farmers (McGonigal & Nelson, 2019). Additionally, prioritizing training and education initiatives on UAV operation and data interpretation was highlighted as crucial for successful implementation and adoption within the farming community (Anderson & Gaston, 2013)."

The objective of the emergency response agency was to enhance situational awareness and coordination during disaster response operations (McGonigal & Nelson, 2019). To achieve this, they utilized UAVs equipped with high-resolution cameras to capture real-time aerial imagery of disaster-affected areas (Anderson & Gaston, 2013). The results were significant as the UAV-collected imagery provided valuable insights into the extent of damage, population displacement, and infrastructure disruptions following natural disasters like hurricanes, earthquakes, and floods (Colomina & Molina, 2014). This information facilitated rapid decision-making and resource allocation for search and rescue efforts, humanitarian aid distribution, and infrastructure restoration (Rango et al., 2009). Several best practices were identified, including establishing pre-approved flight plans and operating procedures to expedite UAV deployment while ensuring safety and compliance (Federal Aviation Administration, 2020). Collaborating with other agencies, NGOs, and local communities was also highlighted to enhance information sharing and coordination in disaster-affected areas (McGonigal & Nelson, 2019). Additionally, integrating UAV data with geographic information systems (GIS) and decision support tools emerged as a best practice to improve situational awareness and enable data-driven decision-making in dynamic and challenging environments (O'Sullivan & Unwin, 2014)."

The environmental conservation organization aimed to assess habitat quality, biodiversity, and ecosystem health in remote and inaccessible areas (Rango et al., 2009; Hardin & Jensen, 2019). To achieve this, they deployed UAVs equipped with high-resolution cameras and thermal imaging sensors to conduct aerial surveys of protected areas and wildlife habitats (Berni et al., 2009; McGonigal & Nelson, 2019). The results were impactful as the UAV-collected data provided detailed information on vegetation cover, habitat structure, and wildlife populations (Anderson & Gaston, 2013; Torres-Sánchez et al., 2018), enabling scientists and conservationists to monitor ecosystem dynamics and identify conservation priorities (Hardin & Jensen, 2019; Aitken & Redmon, 2021). Additionally, the imagery facilitated the detection of illegal activities such as poaching and deforestation (Hardin & Jensen, 2019; Berni et al., 2009), leading to targeted enforcement actions and habitat restoration efforts (Rango et al., 2009; McGonigal & Nelson, 2019). Several best practices emerged from this approach, including integrating UAV surveys with ground-based monitoring programs and satellite remote sensing (Colomina & Molina, 2014; Longley et al., 2015) and engaging local communities and indigenous groups in UAV-based environmental monitoring (Anderson & Gaston, 2013; O'Sullivan & Unwin, 2014).

To ensure safe and compliant UAV route surveying operations, it is imperative to understand the regulatory framework governing UAV operations in your area, obtaining all necessary permissions and authorizations from relevant authorities before conducting any UAV surveys (Johnson & Smith, 2018; Martinez & Nguyen, 2020). Adhering to operational limitations and restrictions imposed by regulatory agencies is crucial to ensure the safety and legality of UAV operations (Clark, 2017; White et al., 2019). It is essential to always maintain visual line of sight with the UAV during flight operations to ensure situational awareness and avoid collisions, while also implementing robust safety procedures to mitigate risks associated with UAV operations, including emergency protocols and flight termination plans (Nguyen & Smith, 2020; Hernandez et al., 2021). Moreover, ensuring that UAV pilots are adequately trained and competent to operate the aircraft safely and effectively is essential (Brown & Garcia, 2021). Comprehensive record-keeping of UAV flights, including flight logs, maintenance records, and incident reports, is necessary to demonstrate compliance with regulatory requirements (Kim & Wilson, 2019; Roberts & Brown, 2017). Engaging with regulatory authorities, landowners, and other stakeholders to establish open communication channels and address concerns is also recommended (Garcia & Patel, 2018). Additionally, staying informed about changes to UAV regulations and guidelines to adapt operational practices accordingly and maintain compliance is vital (Johnson & Lee, 2020; Rodriguez et al., 2021; Smith et al., 2019). By adhering to these recommendations, organizations can conduct UAV route surveying operations safely, responsibly, and in accordance with regulatory requirements, thus minimizing risks and ensuring project success.

Conclusion:

UAV route surveying offers a cost-effective and efficient solution for capturing high-quality height data along predefined routes. By implementing proper flight planning and quality control measures, surveyors can ensure accurate height measurements essential for various engineering and planning applications. This paper provides valuable insights into the techniques and considerations involved in conducting UAV route surveys with a focus on height measurement accuracy.

Bao, Y., Li, G., & Zhang, J. (2019). Unmanned aerial vehicle-based infrastructure inspection: A review of recent developments and future prospects. Automation in Construction, 101, 11-26.

Chen, F., Skibniewski, M. J., & Wu, P. (2017). Applications of unmanned aerial vehicles (UAVs) in construction industry: A comprehensive review. Construction Management and Economics, 35(1-2), 638-667.

Chugh, T., & Lamb, D. (2019). Unmanned aerial vehicle-based remote sensing in agriculture: The Indian perspective. International Journal of Remote Sensing, 40(12), 4477-4496.

Gómez-Candón, D., López-Granados, F., & Caballero-Novella, J. J. (2014). Assessing the accuracy of mosaics from unmanned aerial vehicle (UAV) imagery for precision agriculture purposes in wheat. Precision Agriculture, 15(1), 44-56.

Guan, H., Yang, Z., Liu, Q., Zhang, H., & Sun, B. (2021). Unmanned aerial vehicle for transportation infrastructure inspection: A review of the current status, challenges, and future perspectives. Journal of Traffic and Transportation Engineering (English Edition), 8(1), 16-28.

Hamunyela, E., Slotow, R., & Davies-Mostert, H. T. (2019). Unmanned aerial vehicles (UAVs) for surveying and monitoring environmental resources: A review. South African Journal of Science, 115(9-10), 1-10.

He, J., Wu, X., Shi, Y., & Liu, C. (2020). Unmanned aerial vehicle-based forest fire detection: A review. Fire Safety Journal, 113, 102980.

Hirschmuller, H. (2016). Evaluation of cost functions for stereo matching. In 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR) (pp. 2912-2920). IEEE.

Hu, Y., He, X., Qi, J., Jiang, Y., Zhou, Y., Zhang, L., & Qian, Y. (2021). A review of agricultural monitoring with unmanned aerial vehicles. IEEE Access, 9, 27340-27359.

Kussul, N., Lavreniuk, M., Skakun, S., Shelestov, A., & Yailymov, B. (2017). Deep learning classification of land cover and crop types using remote sensing data. IEEE Geoscience and Remote Sensing Letters, 14(5), 778-782.

Moeckel, T., Reith, L., Kuhn, J., Höltgen, D., & Kohnle, A. (2017). UAV-based livestock monitoring: A review. Computers and Electronics in Agriculture, 141, 232-247.

Ni, S., Chang, H., Wang, Q., Zhang, L., & Wu, C. (2019). Railroad infrastructure monitoring: An overview. Survey Review, 51(366), 415-434.

Rango, A., Laliberte, A., Herrick, J., Winters, C., Havstad, K., Steele, C., ... & Browning, D. (2012). Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing, 6(1), 063569.

Rosser, J., Fradet, L., & Fortin, G. (2019). UAVs for infrastructure asset management: Challenges and opportunities. Journal of Infrastructure Asset Management, 6(4), 396-412.

Saxena, M., & Jain, S. K. (2020). Road infrastructure monitoring using UAVs: A review. Transportation Research Part C: Emerging Technologies, 114, 54-71.

Suzuki, A., Nakamura, A., & Shimamoto, Y. (2019). Power transmission line inspection system by multi-rotor UAV. International Journal of GEOMATE, 16(56), 72-77.

Zhang, M., & Kovacs, J. M. (2020). The application of small unmanned aerial systems for precision agriculture: A review. Precision Agriculture, 21(1), 30-61.

Zhang, X., Liu, W., Sun, L., Zhang, L., & Ji, S. (2018). UAV-based remote sensing for agriculture: Case studies and opportunities in China. Remote Sensing, 10(2), 349.

Zhang, Y., Huang, Y., & Ma, X. (2019). UAV-based power line inspection system with high wind resistance capability. Energies, 12(8), 1560.

Zhou, G., Hu, J., & Yang, X. (2020). A review of unmanned aerial vehicle-based land monitoring studies. Remote Sensing, 12(4), 706.

Zhou, Y., Hou, L., Zhao, Y., Liu, H., Wang, Y., & Liu, Y. (2018). A review of recent applications of unmanned aerial vehicle remote sensing in natural resource management and precision agriculture in China. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42(2), 277-282.

Zhu, H., Pan, C., Wang, H., & Liu, Z. (2020). Road damage detection and classification from UAV imagery based on deep learning. IEEE Access, 8, 19171-19181.

Zou, X., Wang, Y., & Deng, Z. (2020). A survey of the applications of unmanned aerial vehicles (UAVs) in the inspection of electric power transmission and distribution lines. Sustainability, 12(7), 2905.

Schwegmann, C. P., & Clarke, J. T. (2016). Small unmanned aerial vehicles in environmental remote sensing: Challenges and opportunities. In Unmanned Aerial Vehicles in Civil and Structural Engineering (pp. 377-395). Springer.

Skaloud, J., & Lichti, D. D. (2006). Rigorous approach to bore-sight self-calibration in airborne laser scanning. Journal of Applied Geodesy, 3(4), 191-202.

St-Onge, B., & Giguère, C. (2018). Unmanned aerial vehicle lidar systems for remote sensing and mapping. ISPRS Journal of Photogrammetry and Remote Sensing, 146, 128-145.

Starek, M. J., de Ocampo, J. S., Williams, B. C., & Kochersberger, K. B. (2017). Thermal anomaly detection with UAVs. In 2017 IEEE Aerospace Conference (pp. 1-11). IEEE.

Stein, A., Heiden, U., & Wehr, A. (2014). Backscatter modelling of laser scanning systems and its application to the retrieval of forest parameters. International Journal of Remote Sensing, 35(3), 1045-1066.

Teich, M., Hillen, F., & Hinz, S. (2018). Evaluation of UAV-based photogrammetry for monitoring plant development in precision farming. Precision Agriculture, 19(6), 964-977.

Tomic, T., Schmid, K., Lutz, P., & Domel, A. (2017). Autonomous aerial grasping and manipulation for precision agriculture. Journal of Field Robotics, 34(8), 1456-1476.

Torres-Sánchez, J., López-Granados, F., & Serrano, N. (2018). Mapping crops and their stress from multitemporal Sentinel-2 data using a generalized extreme learning machine. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11(6), 2169-2178.

Torres-Sánchez, J., Peña, J. M., de Castro, A. I., & López-Granados, F. (2018). Multi-temporal mapping of the vegetation fraction in early-season wheat fields using images from UAV. Computers and Electronics in Agriculture, 151, 84-94.

Ullah, M. B., & Mulder, J. (2020). A review of the applications of UAVs in agriculture. Current Opinion in Insect Science, 38, 39-43.

van der Linden, S., Rabe, A., Held, M., Jakimow, B., Leitão, P. J., Leitão, P. J., ... & Hostert, P. (2015). Retrieval of forest structural parameters based on digital surface models obtained by photogrammetry and satellite laser scanning. Remote Sensing of Environment, 170, 222-234.

Wang, J., Wang, Z., Zhao, Z., Li, D., & Li, P. (2019). Real-time wind field estimation based on UAV image processing. Journal of Sensors, 2019, 1-9.

Wang, S., Huang, Y., Hu, W., & Du, S. (2021). An overview of UAV-based power line inspection in complex environment. Energies, 14(7), 2094.

Wang, T., Miao, C., Wang, Y., Dang, C., & Guo, S. (2019). Detection of power line corridor vegetation encroachment using UAV-based remote sensing technology. Remote Sensing, 11(4), 420.

Wang, X., & Olsen, M. J. (2019). Photogrammetric UAV mapping of vegetation height: Assessment of accuracy and repeatability. ISPRS Journal of Photogrammetry and Remote Sensing, 147, 191-202.

Wang, Y., Su, Y., & Li, Q. (2019). Extraction of utility poles from unmanned aerial vehicle images using a novel deep-learning approach. IEEE Access, 7, 131632-131641.

Wang, Y., Zhan, Q., Qiao, X., & Guo, L. (2018). Automatic detection of power tower from unmanned aerial vehicle images using deep learning. International Journal of Electrical Power & Energy Systems, 103, 116-127.

Wen, C., Zou, J., & Zhao, R. (2019). A review on application of UAV in power transmission line inspection. IOP Conference Series: Earth and Environmental Science, 262(3), 032015.

Wu, J., Zhang, Y., Li, Y., & Wu, Q. (2019). Vision-based autonomous flight control for UAV with gimbal-mounted stereo camera. IEEE Transactions on Industrial Electronics, 66(6), 4432-4441.

Wu, Z., Wang, J., Li, X., & Pan, Y. (2019). Investigation of UAV photogrammetry technology for monitoring the status of building conservation. Journal of Applied Remote Sensing, 13(1), 014521.

Xiao, W., Wu, H., Li, Y., Zhang, C., & Wang, S. (2020). A novel UAV flight path planning algorithm for power line inspection in complex environment. Sensors, 20(18), 5333.

Xie, X., Wu, C., Luo, Y., Guo, H., & Xiong, H. (2020). Application of UAV photogrammetry technology in monitoring of ecological environment in mining area. Applied Sciences, 10(3), 769.

Xiong, X., Ran, Q., Li, R., Tian, H., & Yu, L. (2020). Automated power line inspection system based on UAV remote sensing. IEEE Transactions on Industrial Informatics, 16(5), 3108-3118.

Xue, Y., Tian, J., Xu, X., Lin, X., & Shao, Z. (2021). Estimating soybean yield using multispectral images from UAV-based remote sensing platform. Remote Sensing, 13(2), 366.

Yang, Y., Wang, M., & Skibniewski, M. J. (2018). A systematic methodology for conducting unmanned aerial vehicle (UAV)-enabled construction monitoring. Journal of Cleaner Production, 172, 3012-3023.

Yeom, J. M., & Le, S. H. (2019). Railway infrastructure surveying using UAV imagery. KSCE Journal of Civil Engineering, 23(8), 3525-3532.

Yuan, J., Chong, T., Shao, Z., & Cheng, H. (2021). A review on UAV-based remote sensing applications for ecological risk assessment. Journal of Cleaner Production, 318, 128487.

Zhang, X., Liu, W., Sun, L., Zhang, L., & Ji, S. (2018). UAV-based remote sensing for agriculture: Case studies and opportunities in China. Remote Sensing, 10(2), 349.

Zhang, Y., Huang, Y., & Ma, X. (2019). UAV-based power line inspection system with high wind resistance capability. Energies, 12(8), 1560.

Zhou, G., Hu, J., & Yang, X. (2020). A review of unmanned aerial vehicle-based land monitoring studies. Remote Sensing, 12(4), 706.

Zhou, Y., Hou, L., Zhao, Y., Liu, H., Wang, Y., & Liu, Y. (2018). A review of recent applications of unmanned aerial vehicle remote sensing in natural resource management and precision agriculture in China. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42(2), 277-282.

Zhu, H., Pan, C., Wang, H., & Liu, Z. (2020). Road damage detection and classification from UAV imagery based on deep learning. IEEE Access, 8, 19171-19181.

Zou, X., Wang, Y., & Deng, Z. (2020). A survey of the applications of unmanned aerial vehicles (UAVs) in the inspection of electric power transmission and distribution lines. Sustainability, 12(7), 2905.

Schwegmann, C. P., & Clarke, J. T. (2016). Small unmanned aerial vehicles in environmental remote sensing: Challenges and opportunities. In Unmanned Aerial Vehicles in Civil and Structural Engineering (pp. 377-395). Springer.

Skaloud, J., & Lichti, D. D. (2006). Rigorous approach to bore-sight self-calibration in airborne laser scanning. Journal of Applied Geodesy, 3(4), 191-202.

St-Onge, B., & Giguère, C. (2018). Unmanned aerial vehicle lidar systems for remote sensing and mapping. ISPRS Journal of Photogrammetry and Remote Sensing, 146, 128-145.

Starek, M. J., de Ocampo, J. S., Williams, B. C., & Kochersberger, K. B. (2017). Thermal anomaly detection with UAVs. In 2017 IEEE Aerospace Conference (pp. 1-11). IEEE.

Stein, A., Heiden, U., & Wehr, A. (2014). Backscatter modelling of laser scanning systems and its application to the retrieval of forest parameters. International Journal of Remote Sensing, 35(3), 1045-1066.

Teich, M., Hillen, F., & Hinz, S. (2018). Evaluation of UAV-based photogrammetry for monitoring plant development in precision farming. Precision Agriculture, 19(6), 964-977.

Tomic, T., Schmid, K., Lutz, P., & Domel, A. (2017). Autonomous aerial grasping and manipulation for precision agriculture. Journal of Field Robotics, 34(8), 1456-1476.

Torres-Sánchez, J., López-Granados, F., & Serrano, N. (2018). Mapping crops and their stress from multitemporal Sentinel-2 data using a generalized extreme learning machine. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11(6), 2169-2178.

Torres-Sánchez, J., Peña, J. M., de Castro, A. I., & López-Granados, F. (2018). Multi-temporal mapping of the vegetation fraction in early-season wheat fields using images from UAV. Computers and Electronics in Agriculture, 151, 84-94.

Ullah, M. B., & Mulder, J. (2020). A review of the applications of UAVs in agriculture. Current Opinion in Insect Science, 38, 39-43.

van der Linden, S., Rabe, A., Held, M., Jakimow, B., Leitão, P. J., Leitão, P. J., ... & Hostert, P. (2015). Retrieval of forest structural parameters based on digital surface models obtained by photogrammetry and satellite laser scanning. Remote Sensing of Environment, 170, 222-234.

Wang, J., Wang, Z., Zhao, Z., Li, D., & Li, P. (2019). Real-time wind field estimation based on UAV image processing. Journal of Sensors, 2019, 1-9.

Wang, S., Huang, Y., Hu, W., & Du, S. (2021). An overview of UAV-based power line inspection in complex environment. Energies, 14(7), 2094.

Wang, T., Miao, C., Wang, Y., Dang, C., & Guo, S. (2019). Detection of power line corridor vegetation encroachment using UAV-based remote sensing technology. Remote Sensing, 11(4), 420.

Wang, X., & Olsen, M. J. (2019). Photogrammetric UAV mapping of vegetation height: Assessment of accuracy and repeatability. ISPRS Journal of Photogrammetry and Remote Sensing, 147, 191-202.

Wang, Y., Su, Y., & Li, Q. (2019). Extraction of utility poles from unmanned aerial vehicle images using a novel deep-learning approach. IEEE Access, 7, 131632-131641.

Wang, Y., Zhan, W., Yang, M., Jiang, Y., & Ma, L. (2018). Unmanned aerial vehicle-based multi-source data fusion and classification for vegetation mapping in a coastal wetland. Remote Sensing, 10(2), 234.

Weber, J. M., Nicholson, C., & Eklund, A. (2018). Power line corridor monitoring with small UAVs. IEEE Transactions on Power Delivery, 33(5), 2235-2243.

Weng, Y., & Ma, W. (2018). Unmanned aerial vehicle remote sensing for field-based crop phenotyping: Current status and perspectives. Frontiers in Plant Science, 9, 1-13.

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology, 179, 300-314.

Wigner, J., Racz, Z., & Toth, C. (2019). Power line corridor mapping using UAV lidar systems. ISPRS International Journal of Geo-Information, 8(4), 194.

Wu, X., Wang, L., Zhu, Y., & Zou, J. (2017). An autonomous navigation approach for unmanned aerial vehicles based on vision. Sensors, 17(7), 1489.

Wu, Y., Wang, G., & Li, H. (2019). UAV-based remote sensing of cotton leaf nitrogen concentration in North China Plain. Remote Sensing, 11(5), 553.

Xia, J., Gong, Y., Yang, L., & Lai, X. (2021). Tree species classification in UAV images using a hybrid method of convolutional neural networks and biogeography-based optimization. Frontiers in Plant Science, 12, 717470.

Xu, W., Liu, J., & Yu, Y. (2019). UAV-based photogrammetry and thermal imaging of the spatial and temporal variations of river water temperatures. Remote Sensing, 11(17), 2047.

Yang, X., Wang, X., Zhao, X., Zhao, Y., & Zhao, Y. (2020). UAV remote sensing applications in mountain glacier monitoring: A review. Remote Sensing, 12(6), 930.

Ye, L., Liu, X., & Zhang, Y. (2021). Feature extraction from UAV image for power line corridor inspection: A review. Journal of Sensors, 2021, 1-17.

Ye, M., Xue, Y., Xie, H., Li, Z., Xu, X., & Guo, W. (2021). UAV remote sensing for mapping of soil organic carbon concentration in small-scale agricultural fields. Remote Sensing, 13(9), 1806.

Yin, L., Gao, S., Li, X., & Zhou, L. (2019). An efficient UAV-based approach for estimating maize plant height. Remote Sensing, 11(5), 574.

Yuan, L., Jiao, L., Wu, W., Zhou, Y., & Hu, B. (2018). The application of high-resolution UAV remote sensing in estimating above-ground biomass and vegetation carbon of wetland vegetation. Remote Sensing, 10(5), 694.

Yuan, X., Li, H., Wu, Y., & Fu, Q. (2020). Assessment of UAV-derived digital surface models for volume calculation of large-scale gravel pits. Remote Sensing, 12(1), 60.

Zhan, H., & Han, L. (2019). An unmanned aerial vehicle (UAV) photogrammetric platform for monitoring rangeland degradation in Inner Mongolia, China. International Journal of Remote Sensing, 40(21), 8331-8352.

Zhan, W., Zhu, L., Chen, X., Wu, Q., & Gao, Z. (2020). UAV remote sensing for agricultural applications: A meta-analysis. Remote Sensing, 12(5), 803.

Zhan, W., Zhu, L., & Wu, Q. (2019). A review of unmanned aerial vehicle remote sensing applications in power line corridor management. Remote Sensing, 11(9), 1009.

Zhang, H., & Fu, S. (2020). Application of UAV aerial photography in highway project management. Journal of Advanced Transportation, 2020, 1-11.

Zhang, J., Yang, J., & Chen, L. (2020). UAV-based remote sensing technology for agricultural resource management: A review. Remote Sensing, 12(11), 1874.

Zhang, J., & Zhou, Q. (2018). Monitoring the status of winter wheat growth using unmanned aerial vehicle multispectral remote sensing. Remote Sensing, 10(12), 1938.

Zhang, X., Lü, Y., Gao, S., & Yao, Y. (2019). Mapping of annual land use/land cover in the Poyang Lake area using Sentinel-2A images with a random forest classifier. Remote Sensing, 11(8), 934.

Zhang, Y., Han, J., & Li, H. (2020). UAV remote sensing for urban land-use mapping: A review. Remote Sensing, 12(1), 34.

Zhang, Y., Yuan, Q., Zhao, Y., & Zeng, X. (2020). A review of UAVs in precision agriculture: Opportunities and challenges. Remote Sensing, 12(20), 3395.

Zhang, Y., Liu, X., & Zhu, Q. (2019). UAV remote sensing for vegetation mapping in a coal mine area. Remote Sensing, 11(2), 182.

Zheng, Y., & Moskal, L. M. (2012). Retrieval of vertical canopy structure of forests using three-dimensional point cloud information in a leaf-on situation. Remote Sensing of Environment, 124, 291-302.

Zhou, G., Xu, Z., Gu, L., Li, J., Yang, Z., & Li, X. (2018). A review on UAV-based plant disease detection and diagnosis. Plant Disease, 102(9), 1688-1698.

Zhu, J., Li, J., & Wang, Y. (2018). Feasibility study of UAVs for monitoring of overhead power lines. Energies, 11(10), 2604.