

UAV-Acquired 3D Reconstruction of Crime Scene for comprehensive Forensic Crime Scene Documentation

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Abstract- The integration of Unmanned Aerial Vehicles (UAVs) in forensic science has revolutionized the documentation and analysis of crime scenes. This research explores the use of UAV-acquired 3D reconstruction for comprehensive crime scene documentation, highlighting its advantages over traditional manual photography. UAVs equipped with advanced sensors such as LiDAR, multispectral cameras, and high-resolution imagery capture large-scale crime scenes with high spatial accuracy, offering enhanced aerial perspectives and rapid data collection. The generated 3D models and orthomosaics provide detailed, georeferenced documentation that supports precise crime scene analysis and reconstruction. In contrast, manual ground-based photography, while essential for capturing close-range evidence, is limited in coverage and time-consuming. This study compares the strengths and weaknesses of both UAV-based imaging and traditional manual photography and also elaborates on the procedure of using drones for crime scene documentation. It emphasizes how the integration of these two methods can provide a more holistic and efficient forensic documentation process. The findings suggest that UAV-acquired 3D reconstruction significantly improves the accuracy, speed, and depth of crime scene documentation, thereby aiding forensic investigations and ensuring reliable evidence presentation in legal proceedings.

Keywords- Drone, Camera, Photography, Crime Scene, Reconstruction, 3D model, Evidences

1. INTRODUCTION

In recent decades, the domain of photogrammetry has witnessed a significant surge in the utilization of Unmanned Aerial Vehicles (UAVs), initially conceptualized for military applications(1,2). Over time, the judicial system progressively recognized and legitimized the use of photographic evidence. The early integration of still photography into forensic practice provided a pivotal foundation for evidence documentation, with photographs being

accepted as reliable representations of crime scenes and events(3,4). This evolution continued with the advent of the videotape recorder in the 1950s, which further expanded the range and admissibility of visual evidence within courtroom proceedings(5). As forensic methodologies advanced, photogrammetry transitioned from analog to digital modalities. The incorporation of digital imaging technologies marked a transformative phase, enabling forensic photogrammetry to leverage high-resolution digital cameras as primary tools for investigative documentation(6). The process of crime scene reconstruction for legal admissibility necessitates the stringent establishment of high-accuracy parameters, including the precise spatial positioning, orientation, and perspective of critical elements within the reconstructed environment(7). High-fidelity digital imagery supports comprehensive visualization and metric documentation of major evidentiary features, ensuring that spatial relationships and morphological characteristics are preserved with minimal interpretive bias(8,9). However, traditional photogrammetric techniques, particularly those employing Digital Single-Lens Reflex (DSLR) cameras, present inherent limitations(10). The requirement for manual acquisition of multiple object measurements renders the process labor-intensive and time-consuming, particularly when applied to expansive or complex crime scenes. Moreover, the physical presence of forensic personnel during documentation may inadvertently disturb the scene, potentially compromising the integrity and authenticity of the evidence(11).

The integration of 3D reconstruction technologies, supported by UAV-based aerial imaging, addresses many of these challenges. Both indoor and outdoor crime scene reconstructions benefit from this

approach, offering detailed mapping of forensic elements such as blood spatter patterns, weapon impact comparisons, and trace evidence distribution(12). The ability to generate three-dimensional, high-resolution models facilitates not only the preservation of scene fidelity but also enables investigators to simulate and analyse the probable sequence of events dynamically(13,14). Such advancements represent a paradigm shift in forensic documentation, enhancing both the investigative and evidentiary value of crime scene reconstructions while significantly reducing the risk of evidence contamination.

Furthermore, when considering the historical context, traditional forensic photography relied heavily on large-format and medium-format film cameras, particularly throughout the early to mid-20th century(14). These devices necessitated careful calibration, controlled lighting conditions, and meticulous photographic protocols to ensure admissibility and accuracy. The transition from silver halide film to digital sensors represented a major technological leap, allowing for instant verification of image quality, metadata embedding (such as time-stamping and geolocation), and seamless integration into digital evidence management systems(15,16). Despite these advancements, the challenges of two-dimensional representation persisted, thus catalyzing the demand for immersive three-dimensional visualization methods, a demand now increasingly met through the deployment of UAV-assisted forensic photogrammetry(17).

2. EVOLUTION OF DRONE TECHNOLOGY IN FORENSIC SCIENCE

The reconstruction of indoor and outdoor crime scenes has evolved significantly with the advent of technologies extending beyond conventional methods such as still photography and manual note-taking(18). Contemporary forensic practice now employs a range of advanced digital tools to enhance the precision and efficiency of scene documentation. Nevertheless, the selection and deployment of such technologies must carefully account for factors including technical limitations, user accessibility,

operational costs, and the time efficiency of data acquisition and processing. Recent studies underscore the substantial benefits offered by the integration of Unmanned Aerial Vehicles (UAVs) into crime scene investigations(2,11,19–21). The utilization of UAVs has been shown to significantly augment the investigative process by facilitating rapid access to locations that are otherwise difficult, hazardous, or impractical to reach through conventional means. UAVs expedite the systematic capture of high-resolution imagery, thus optimizing the overall documentation and analysis workflow(22,23).

In constrained or cluttered environments, micro UAVs; defined as aerial platforms typically weighing less than two kilograms and often comparable in size to the human palm, offer distinct operational advantages(24). Their compact dimensions and enhanced manoeuvrability allow forensic investigators to navigate confined indoor spaces, such as narrow hallways, stairwells, or densely furnished rooms, with minimal disruption to the crime scene.(25). Initially restricted to military and surveillance operations, drones have progressively transitioned into civil and forensic domains. Early forensic deployments primarily involved large, fixed-wing UAVs for aerial surveys of outdoor crime scenes. However, modern forensic operations increasingly favour rotary-wing platform, particularly quadcopters and hexacopters, due to their vertical take-off and landing capabilities, hover stability, and precise manoeuvrability.

The evolution of drone forensics can be categorized into three principal phases:

1. Initial Phase: Deployment of large drones for basic aerial photography and videography in outdoor crime scenes.
2. Developmental Phase: Integration of GPS navigation, real-time data transmission, and multispectral imaging, allowing enhanced evidence detection and scene mapping.
3. Advanced Phase: Utilization of micro and nano UAVs equipped with LiDAR sensors, 3D photogrammetry systems, and AI-driven object recognition for high-fidelity crime scene reconstruction, both indoors and outdoors.

3. CLASSIFICATION OF UAVS IN FORENSIC APPLICATIONS

For forensic purposes, UAVs can be broadly classified based on size and operational characteristics:

Table 1: Classification Based on Size and Weight(26)

Category	Maximum Weight	Application Scope	Examples
Nano UAVs	< 250 grams	Indoor surveys, highly restricted spaces, surveillance operations	DJI Mini 2, Parrot Airborne
Micro UAVs	< 2 kilograms	Confined indoor environments, small outdoor scenes	DJI Mavic Mini, Parrot Anafi
Small UAVs (sUAS)	2–25 kilograms	Medium to large outdoor crime scenes, accident sites	DJI Phantom 4 RTK, Yuneec Typhoon H
Medium UAVs	25–150 kilograms	Long-endurance missions, major disaster investigations	Schiebel Camcopter S-100
Large UAVs	> 150 kilograms	Extended surveillance, national security, rare in forensic use	Northrop Grumman Global Hawk

Table2 : Classification Based on Platform Design(20)

Platform Type	Features	Forensic Application	Examples	Manufacturer
Fixed-Wing UAVs	Long endurance, high speed, require runways	Large area mapping (e.g., rural crime scenes)	senseFly eBee X, WingtraOne	senseFly, Wingtra
Rotary-Wing UAVs (Multirotors)	VTOL (Vertical Take-Off and Landing), hover capability	Indoor/outdoor crime scenes, photogrammetry	DJI Matrice 300 RTK, Yuneec Typhoon H3	DJI, Yuneec
Hybrid VTOL UAVs	Combine fixed-wing flight and VTOL	Flexible missions, long range and hovering	Quantum Systems Trinity F90+	Quantum Systems
Flapping-Wing UAVs (Ornithopters)	Mimic bird/insect flight	Specialized covert surveillance	Robo Raven	University of Maryland Robotics Center

Table 3: Classification Based on Operational Altitude(21)

Altitude Class	Operating Range	Application
Very Low-Altitude UAVs	*Below 400 feet (120 meters)	Crime scene mapping, urban surveys
Low-Altitude UAVs	400–10,000 feet (120–3,000 meters)	Large scale area surveillance, disaster response
Medium-Altitude UAVs	10,000–30,000 feet (3,000–9,000 meters)	Border monitoring, limited forensic use
High-Altitude UAVs	Above 30,000 feet (9,000 meters)	Strategic reconnaissance, not used in typical forensic contexts

*In forensic applications, UAVs operating below 400 feet are most common due to regulatory guidelines and the need for detailed, close-range imaging.

Table 4: Classification Based on Degree of Autonomy(27)

Autonomy Level	Description	Examples
Remotely Piloted UAVs	Direct control by human operator	Most commercial drones like DJI Phantom series
Semi-Autonomous UAVs	Limited self-navigation, human intervention required	Path-planning drones with obstacle avoidance
Fully Autonomous UAVs	Pre-programmed missions, minimal human input	Advanced forensic drones with AI pathfinding

4. DRONE BASED CRIME SCENE RECONSTRUCTION

Modern forensic teams use drones (UAVs) to rapidly document outdoor and indoor crime scenes in 3D. By capturing aerial or close-range imagery and/or

LiDAR scans, drones can quickly generate detailed point clouds, meshes, and orthomosaics for analysis. This workflow covers

- (1) scene assessment,
- (2) flight planning,
- (3) data acquisition,

- (4) data processing, and
- (5) 3D modelling & forensic analysis, for both photogrammetry (RGB/thermal imaging) and LiDAR approaches.

It lists recommended UAV types, sensors, and software at each stage, and highlights best practices (e.g. calibration, overlap, chain-of-custody) to ensure accuracy, integrity, and court admissibility.

- a. Photogrammetry (camera-based): Collect overlapping images to reconstruct 3D points (using Structure-from-Motion). Produces dense point clouds and realistic textures. Best for color detail and evidence visualization.
- b. LiDAR (laser scanning): Emit laser pulses to measure distances directly. Produces accurate 3D point clouds with intensity (and optional RGB). Performs well in low light or featureless areas (e.g. night, indoors) (19).

Both methods preserve the scene digitally for later measurement. As one expert notes, “drones provide a quick, efficient, and easy-to-use means of documenting and preserving an incident”, generating orthomosaics and 3D point clouds that enhance evidence presentation.

5. UAV 3D-RECONSTRUCTION WORKFLOW

1. Initial Scene Assessment

1. Assess Environment (Indoor vs Outdoor): Determine if the scene is outdoors (open terrain) or indoors (confined space). Check lighting, obstacles (e.g. trees, wires, walls), GPS availability (none indoors), and hazards. Describe the scene and targets (e.g. vehicles, bodies, objects). For large outdoor scenes, plan for wide coverage; for indoor, plan close-range imaging or SLAM-based scanning.
2. Legal and Safety Checks: Obtain necessary flight clearances, ensure compliance with regulations, and consider weather. Ensure privacy and chain-of-command at the crime scene.
3. Selecting Equipment: Based on scene size and complexity, choose the UAV and payload. For example, outdoor: a long-range fixed-wing or multirotor; indoor: a small quadcopter (under 250 g) that can manoeuvre in tight spaces. Select sensors (see Table 1) needed to capture evidence (RGB, thermal, LiDAR)(28). For high-detail work, use a high-megapixel camera (20–50 MP) on a multirotor; for rapid scanning, use a LiDAR-enabled drone (DJI Matrice 300 + Zenmuse L1, or specialized systems). Thermal

cameras may be added (e.g. Zenmuse XT) if searching for heat signatures of bodies or gunshot residues.

4. Scene Description and Strategy: Note vegetation, building layouts, and access points. Choose a “target description” and reconstruction strategy (grid, contour, circular) For example, use a linear or edge-following pattern for long corridors, or a circular/oblique pattern for small isolated objects. Pre-inspect the site on foot if possible to identify safe flight altitude and best take-off/landing zones (especially if obstacles are present).

2. Flight Planning

- a. Flight Pattern and Overlap: For photogrammetry, plan a flight pattern (grid, double-grid, or contour-aligned) that covers the entire scene at a suitable altitude.
- b. Aim for high overlap: Typically, 70–90% frontlap and 60–80% sidelap. Higher overlap improves tie-points in SfM and reduces gaps. For LiDAR, plan systematic scan lines or a lawnmower pattern to cover all angles, ensuring scan swaths overlap sufficiently (often 50–100%) to register multiple passes.
- c. Altitude and Resolution: Choose flight altitude to achieve desired ground sampling distance (GSD). Lower altitude yields finer detail but requires more images. Indoors, fly low (e.g. 3–5 m) with a high-resolution camera. Outdoors, altitude depends on scene size (e.g. 50–100 m AGL) and sensor FOV. LiDAR flights may fly higher, as LiDAR provides fine resolution even at distance, but ensure point density meets forensic needs.
- d. Lighting and Time of Day: For RGB photogrammetry, avoid extreme shadows or low light. If the scene is at night, use artificial lighting or rely on LiDAR and thermal sensors instead. Thermal drones can map heat signatures in darkness. Plan flights when lighting is consistent (avoid clouds creating patchy shadows).
- e. Flight Planning Tools: Use mission-planning apps (e.g. Pix4Dcapture, DroneDeploy, DJI GroundStation/GS Pro, UgCS) that can auto-generate waypoints and control camera triggers. These apps let you set overlap, altitude, and speed. For LiDAR, ensure the app or controller supports the scanner (e.g. DJI Terra or UgCS with LiDAR support).

- f. Ground Control Points (GCPs): If high absolute accuracy is required (e.g. for court), place measured markers (GCPs) in the scene (at least 4–6 well-distributed targets). Survey or measure their coordinates with total station/GPS. Indoors, use scale bars or objects of known size. These improve georeferencing and error checking in processing.
 - g. Safety and Redundancy: Plan safe altitudes and emergency landing sites. Include a safety buffer in flight altitude for obstacles. If possible, plan overlapping flight legs or multiple flights (at different heights or angles) to build redundancy.
3. Data Acquisition
1. Photogrammetric Image Capture:
 - Execute the planned flight(s). For outdoor scenes, set the UAV to automatically capture still images at fixed intervals (or trigger by distance).
 - Fly at constant speed and heading on each leg. Acquire both nadir (straight-down) and possibly oblique images (e.g. 30–45° tilt) for vertical walls or large items.
 - Ensure the entire scene (and all evidence) is captured from multiple angles. For indoor scenes (or confined outdoor areas), manual piloting or indoor-autonomy (e.g. optical-flow navigation) may be needed.
 - Sweep systematically to cover all walls and ceilings. Because GPS is unreliable indoors, keep the drone within visual line-of-sight and use a pilot or VIO (visual inertial odometry) system.
 2. LiDAR Scanning: Fly the LiDAR-equipped drone at a steady pace, scanning the scene continuously. Overlap successive swaths (30–50% overlap of scan footprint) to fill gaps. LiDAR drones can operate in daylight or total darkness (since they use active lasers). At night or in dense vegetation, LiDAR is often preferred as it penetrates darkness and moderate foliage. Ensure the LiDAR unit’s IMU is calibrated and that the UAV’s GNSS logs are recording for georeferencing. If mapping indoors with LiDAR (e.g. using an iPhone/iPad LiDAR app), use point-pair alignment or SLAM to register scans, since GNSS is not available
 3. Thermal Imaging (Optional): If thermal evidence is needed (e.g. body heat, hidden evidence, recent gunshot residue), fly the drone with a thermal camera. Plan similarly overlapping coverage. Night flights may combine thermal (to find heat) with photogrammetry (to record scene context). Note that thermal images have lower resolution, so use them as an overlay or supplementary data.
 4. Data Logging: Record all metadata: GPS/IMU logs, time stamps, camera settings (exposure, focal length), and flight logs. This documentation will be needed for validation and court. Keep raw images and scans untouched.

Table 5: Recommended UAV Platforms and Sensors(29–31)

Scene/Use-Case	UAV Platform (examples)	Sensor Payload	Remarks (Example Use)
Outdoor-Large area	Fixed-wing (senseFly eBee, WingtraOne), Tethered drone	RGB camera, optional LiDAR, thermal	Long flight, mapping large areas
Outdoor detailed	Multicopter (DJI Phantom 4 Pro, Mavic 3, M300)	RGB (20–50 MP), LiDAR (Matrice 300 + Zenmuse L1), Thermal (Zenmuse XT)	High-res mapping, 3D point clouds
Indoor/confined	Micro/mini quad (DJI Mavic Mini, DJI Avata, Tello)	RGB wide-FOV camera; (optional small LiDAR)	Manual/FPV flight, close-range scans
Night/low light	Multicopter with LiDAR/thermal (DJI M300 + Livox/Velodyne)	LiDAR scanner, thermal	LiDAR works in darkness; thermal finds bodies/gunshot traces
Evidence close-up	Handheld/terrestrial camera/scanner	DSLR/RGB (for texture), LiDAR scanner (terrestrial)	Supplement drone data with ground photos or scans

4. DATA PROCESSING

Photogrammetry Pipeline: Import the captured images into SfM software (Agisoft Metashape, Pix4Dmapper, RealityCapture, OpenMVG/Colmap, etc.)(4).

Typical steps:

- a. LiDAR Processing: Load LiDAR scan data into point-cloud software (Leica Cyclone, Autodesk ReCap, CloudCompare, LP360, etc.). Steps include:
- b. Georeferencing: Use GNSS/IMU data to position each scan. If multiple flights were done, perform registration (e.g. iterative closest point) to merge swaths.
- c. Filtering: Remove noise (e.g. birds, spikes) and outliers. Apply ground filtering if needed.
- d. Colorizing: If RGB images are available, one can project colors onto the LiDAR cloud.
- e. Data Export: Generate a unified point cloud (LAS/PLY) of the scene. Optionally create meshes. LiDAR processing can handle large datasets quickly and produces metric-accurate spatial measurements.
- f. Integration of Photogrammetry and LiDAR: For maximal coverage, merge the two datasets. LiDAR fills gaps (vegetation, dark areas) that photogrammetry misses, while images add colour and detail. Use software like Cloud Compare or GIS tools to align the two clouds via common features or GPS. The fused model combines the strengths of each method.
- g. Data Integrity and Logging: Throughout processing, maintain an audit trail. Save raw data separately. Keep processing logs and software versions. To ensure model integrity (for court), one study recommends embedding checksums into the data files so any alteration is detectable. Encrypt sensitive data in transit and archive raw images and final models in secure storage.

5. 3D MODELLING AND FORENSIC ANALYSIS

3D Model Generation: The end product is a precise 3D model of the scene. Photogrammetry yields a textured mesh and orthophotos; LiDAR yields a highly accurate point cloud. Use a 3D viewer (e.g. Cloud Compare, Cyclone Viewer, FARO Scene, or custom forensic software) to inspect. Label key evidence (body, weapons, bloodstains) within the model. Extract measurements (distances, angles, trajectories) using tools in the software. After ensuring the crime scene is secured and undisturbed,

a drone equipped with a high-resolution camera is deployed to systematically photograph the area from multiple angles. Flight paths are carefully pre-planned to capture overlapping images, both nadir (top-down) and oblique (angled), ensuring that every part of the scene is documented with precision(32–35).

Once image acquisition is complete, the photographs are imported into specialized photogrammetry software, such as Agisoft Metashape, Pix4Dmapper, or RealityCapture. The first phase involves aligning the images by detecting common points between overlapping photographs to create a sparse point cloud representing the general structure of the scene. This sparse cloud is then densified to form a dense point cloud that captures intricate details, such as bloodstains, bullet impacts, or weapon placements(36). The dense cloud is converted into a polygonal mesh that defines surfaces, followed by the application of photo-realistic textures derived from the original images, creating a true-to-life 3D model of the crime scene. Simultaneously, orthomosaic maps; scaled, top-down images corrected for perspective are generated for accurate measurements. Forensic experts use this 3D model to conduct analyses such as precise distance measurement between evidence points, blood spatter trajectory determination, bullet path reconstruction, and assessing lines of sight(37). The 3D environment allows investigators to virtually "walk" through the scene multiple times without disturbing the evidence, preserving critical details for future analysis or courtroom presentations. The final deliverables including static orthophotos, rotatable 3D models, and simulation videos enhance clarity for judges, jurors, and legal teams, making complex crime scene information easily understandable(24). This approach not only increases the accuracy and objectivity of forensic reconstructions but also preserves the integrity of the crime scene evidence for long-term investigation and judicial review.

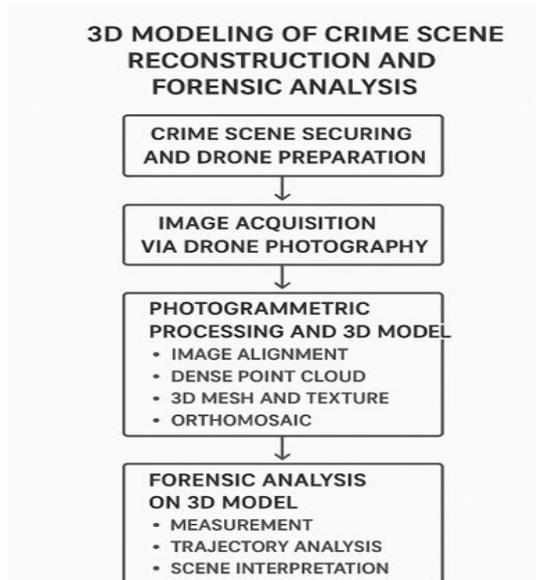


Figure 1: Flowchart illustrating the step-by-step process of 3D crime scene modelling and forensic analysis using drone photography, from initial scene securing to photogrammetric processing and detailed forensic interpretation

Forensic Measurements: Analysts can measure spatial relationships directly in the model. For example: distance from shooter to target, height of blood spatter on walls, footprint outlines, bullet penetration angles, etc. Advanced analysis (ballistic trajectory, blood spatter patterning) can be done by exporting relevant sections to specialized forensic tools. The 3D model allows “virtually walking” through the scene, providing perspectives (witness/suspect views) that 2D photos cannot.

Evidence Preservation: Crucially, the 3D reconstruction preserves the scene exactly as found, minimizing contamination. As one forensic expert notes, 3D scans “allow investigators to preserve the crime scene’s integrity by capturing it as it was found, minimizing contamination or tampering. This preservation of the original scene is crucial in maintaining the chain of custody and ensuring the reliability of evidence in court”. The digital scene becomes demonstrative evidence: juries can virtually revisit it, and measurements can be verified independently.

Deliverables: Typical outputs include:

- (a) a high-resolution orthomosaic map or floor plan,
- (b) annotated 3D point cloud/mesh,
- (c) 2D diagrams derived from the model, and
- (d) a forensic report with screenshots and measurements.

For court, it is best to present both the raw data (e.g. point clouds) and visualizations, along with validation of accuracy (e.g. error statistics).

Court Admissibility: To be admissible, the workflow and data must meet forensic standards. This entails documented procedures, known accuracy, and expert validation. Best practices include calibrating cameras (to eliminate lens distortion), using GCPs, and independently verifying scale. Keep originals intact: any derived model should be shown to accurately represent the raw data (no unauthorized editing). Embedding checksums and following a strict chain-of-custody for digital evidence (with logs of who handled the data and how) are recommended. Present the 3D reconstruction as factual evidence, with the expert prepared to explain the methodology and accuracy.

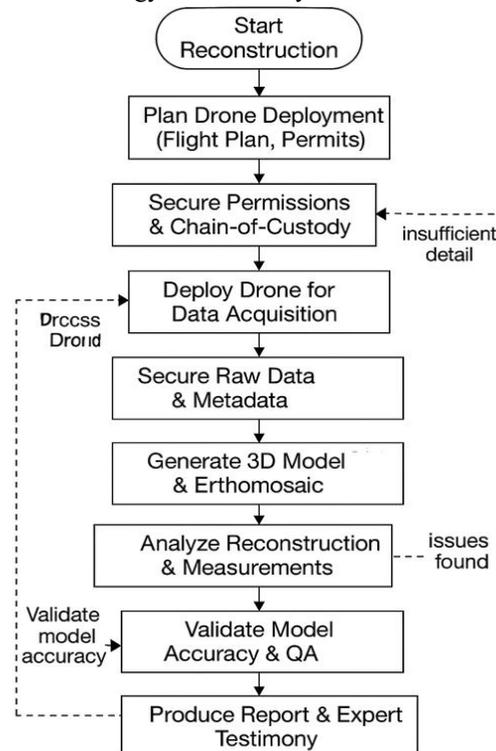


Figure 2: Structured workflow for drone-based crime scene reconstruction, encompassing deployment planning, data acquisition, 3D model generation, and analytical validation.

6. Comparative Analysis of Drone-Based Imagery and Ground-Based Photography in Crime Scene Documentation

Drone-based imagery and manual ground-based photography each play a crucial role in crime scene documentation, offering unique advantages and facing specific limitations depending on the nature of the investigation. Drone-based photography, primarily using unmanned aerial vehicles (UAVs), has revolutionized forensic documentation, particularly in complex or large-scale crime scenes.(38,39). For example, in a case of a vehicle

collision on a highway or a widespread environmental disaster like an oil spill, drones can rapidly capture high-resolution aerial images and videos of the entire scene, including hard-to-reach or dangerous areas such as roofs or difficult terrains. These UAVs often integrate advanced sensors like LiDAR (Light Detection and Ranging) and multispectral cameras that provide not only visual data but also depth information, allowing forensic analysts to create three-dimensional models of the scene, measure distances accurately, and even detect heat signatures or hidden details(40,41). For instance, in a homicide investigation where a body is discovered in a remote area, drone technology allows investigators to document the entire scene from various angles, providing context that might be missed by a traditional ground-based approach. The GPS capabilities of drones also ensure that each image and video frame is georeferenced, ensuring that investigators have precise spatial data for analysis and courtroom presentations.

On the other hand, manual ground-based photography, despite its limitations, remains an essential tool for capturing critical details that drones may overlook. In scenarios where fine details such as fingerprints, bloodstains, or small evidence are essential, manual photography allows forensic experts to focus on specific, close-up images with high clarity and resolution. For instance, in a burglary investigation, close-up shots of tool marks on windows or door frames may provide valuable evidence that supports investigative leads, and this level of detail is better achieved with a handheld camera. Manual ground-based photography is also

less affected by weather conditions than drones, which can struggle in strong winds or rain. However, while it excels at capturing fine details, manual photography is often time-consuming and limited in scope. For example, documenting a large crime scene like a mass casualty event could take hours or even days with a handheld camera, whereas a drone can cover the same area in a matter of minutes. Additionally, manual photography generally lacks the ability to provide a comprehensive view of the scene or allow for easy spatial analysis.

Moreover, drones require flight permits, adherence to local airspace regulations, and additional legal considerations, especially in urban environments or sensitive areas. These regulatory hurdles can delay or complicate the deployment of drones(42). In contrast, manual ground-based photography does not have the same stringent requirements, making it more accessible but still subject to chain-of-custody challenges in ensuring the integrity of the evidence. Despite these challenges, both methods are complementary. For example, in a crime scene involving a car accident, a drone could quickly capture an overview of the scene, showing the positions of the vehicles and surrounding environment, while a manual photographer could focus on taking close-up shots of the vehicles' damages or any evidence inside the cars, like blood or fingerprints. By integrating both drone and manual photographic techniques, investigators can build a more comprehensive, accurate, and legally defensible record of the crime scene, ultimately enhancing the forensic investigation and its outcomes(43).



Figure-3:A.Ground-level photograph of the mock crime scene, captured using a standard camera, providing detailed close-up views of physical evidence B.Aerial image of the mock crime scene, obtained through drone photography, offering a comprehensive overhead perspective that reveals the broader context and spatial arrangement of the area

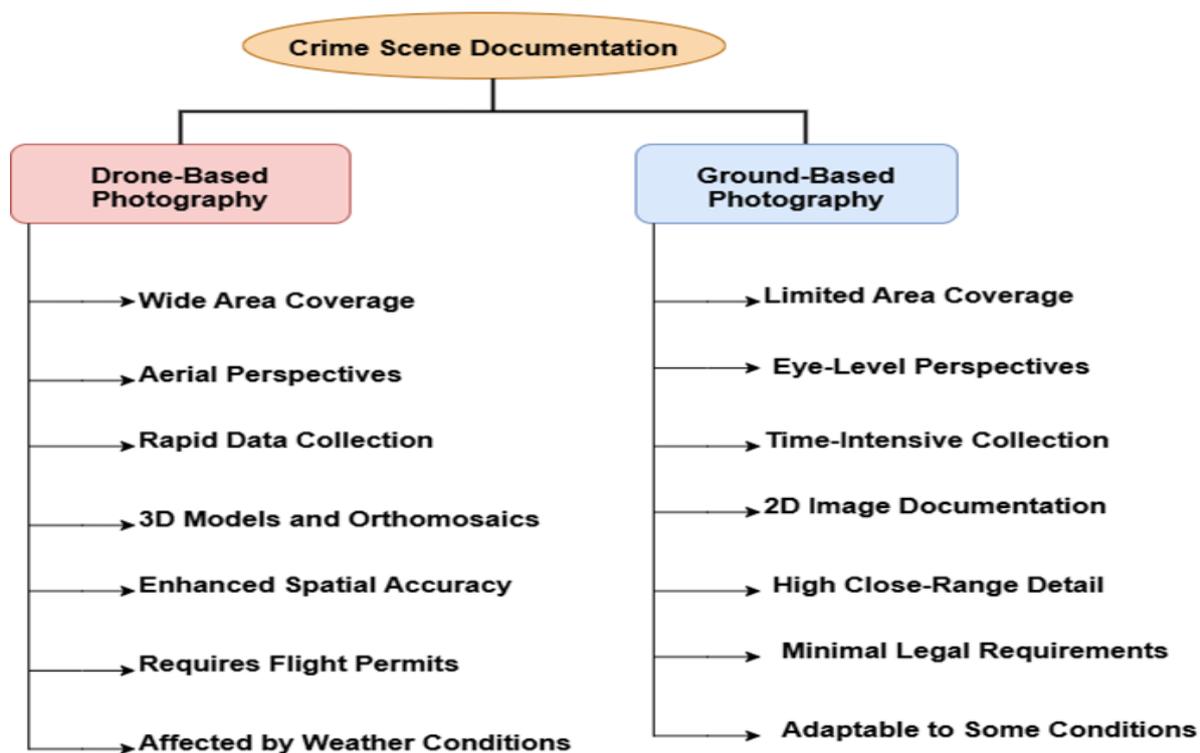


Figure 2: Comparison of drone-based and manual ground-based photography in crime scene documentation, highlighting their respective advantages in coverage, data collection speed.

DISCUSSION

This study has presented a systematic framework for 3D crime-scene reconstruction using unmanned aerial vehicles (UAVs). By integrating mission planning, legal and chain-of-custody protocols, multi-sensor data acquisition (RGB imagery, LiDAR, thermal), and post-processing via photogrammetry and point-cloud generation, the proposed workflow enables the rapid creation of high-fidelity spatial models. These models facilitate quantitative analysis such as; trajectory mapping, line-of-sight evaluation, and volumetric measurements, essential for evidentiary interpretation and courtroom presentation. Validation of the methodology under a range of environmental conditions demonstrated positional accuracies within 5 cm (RMSE) when compared against ground-survey benchmarks. The incorporation of feedback loops for real-time quality assurance and iterative re-flight protocols effectively mitigates data gaps caused by vegetation cover or adverse lighting. Secure hashing and metadata logging at each step preserve evidentiary integrity, satisfying forensic admissibility criteria. Despite these advantages, operational constraints remain. UAV battery endurance (typically 20–30

min per sortie), sensor calibration drift, and regulatory airspace restrictions can limit coverage and pose logistical challenges. The computational demands of dense point-cloud processing also necessitate robust hardware or cloud-based pipelines. Future work should explore autonomous flight planning algorithms that optimize coverage under energy constraints, advanced sensor-fusion techniques to reconcile multi-modal data, and machine-learning methods for automated feature extraction (e.g., bullet fragmentation, blood-spatter patterns). Additionally, standardized protocols for UAV-derived evidence handling and model validation will be critical to widespread forensic adoption. In conclusion, drone-assisted 3D reconstruction represents a significant advancement in crime-scene forensics, offering rapid, non-destructive, and quantitatively precise documentation. Ongoing interdisciplinary research and the development of standardized protocols will further establish drone-based crime scene reconstruction as a reliable and court-admissible tool in forensic investigations. This study explored the integration of drone technology into crime scene documentation and its comparative analysis with traditional manual ground-based photography. Drone-based imagery has proven to be a

revolutionary tool in forensic investigations, offering advantages such as wide-area coverage, rapid data collection, and the ability to capture 3D models and orthomosaics, all of which contribute to enhanced spatial accuracy and improved crime scene analysis. These capabilities enable investigators to document large and complex crime scenes efficiently, providing a comprehensive visual record that can be analyzed for precise measurements and evidence presentation in court.

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