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REVIEW ARTICLE

Drone: A Smart Intelligent Framework Aiding Forensic Investigations

Mahak[1], Sahil Deswal[2], Jaskaran Singh[3], Ananya G.[4], Sahil Sharma[5]

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ABSTRACT

UAV's (Unmanned Aerial Vehicles) named Drones are playing significant role in the field of forensic sciences. Primarily, the utilization of these drones for crime scene investigation is served lot of forensic charm. Furthermore, its application in diverse fields of forensic sciences is efficiently yielding importance for criminal investigation. In this review an attempt has been made to portray applicability of forensic drones in various disciplines of forensic science such as photogrammetry, CSI, proactive forensics.

KEYWORDS

• Drones • Unmanned aerial vehicles • Photogrammetry • Proactive forensics

INTRODUCTION

A drone is a model configured with remotely controlled software and sensors in association with GPS. These remotely controlled GPS models/structures are widely utilized in the field of forensic sciences.[1] Starting from crime scene surveillance till documentation, this real time monitoring aids in investigation by providing virtual presence of investigating officer at crime scene. Nonetheless, These UAV (Unmanned Aerial Vehicle) are not only prompt investigating officers it also covers the range of different forensic specializations such as in military forensics, Wildlife, Mass Disaster etc.[2,3]

This UAV (Unmanned aerial vehicle) structure i.e. drone shall able to meet all legal guidelines which is being ably followed and utilized in various forensic applications. The criteria of drone in legal context and ordinances are governed by drone rules 2021 issued by Directorate General of Civil Aviation DGCA

AUTHOR'S AFFILIATION:

[1] Student, M.Sc. Forensic Science, Geeta University, Panipat, Hayana, India.
[2] Student, M.Sc. Forensic Science, Geeta University, Panipat, Hayana, India.
[3] Professor, School of Sciences, Geeta University, Panipat, Hayana, India.
[4] Assistant Professor, School of Sciences, Geeta University, Panipat, Hayana, India.
[5] Assistant Professor, School of Sciences, Geeta Univeristy, Panipat, Hayana, India.

CORRESPONDING AUTHOR:

Sahil Sharma, Assistant Professor, School of Sciences, Geeta Univeristy, Panipat, Hayana, India.

E-mail: sahilsharma1277@gmail.com

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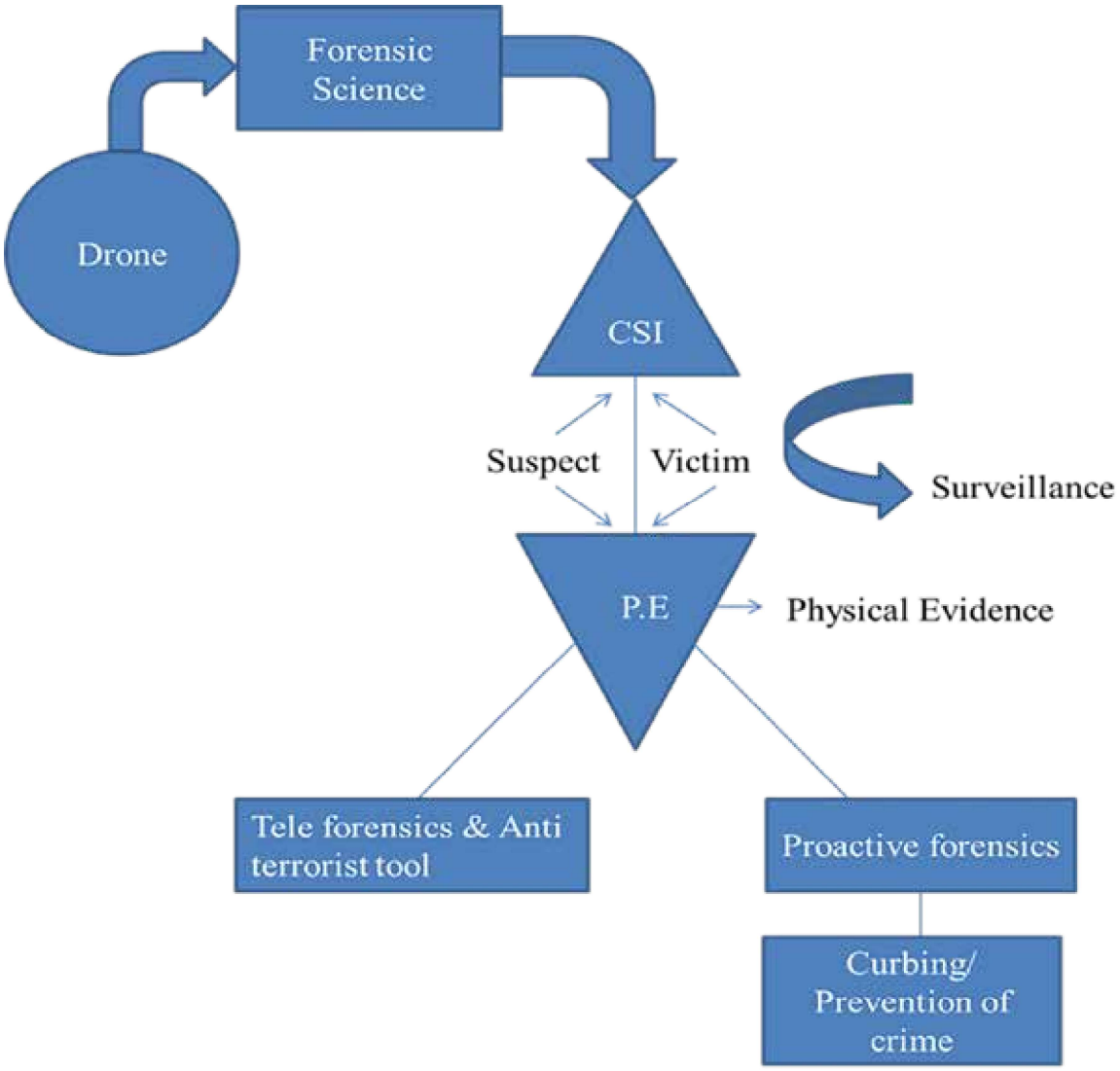
under ministry of civil aviation, Government of India. It covers the functionality, Registration, Licensing, operation requirement and restriction.[4] Drones are not allowed to fly over specific places, including as military installations, nuclear reactors, dams, and other critical locations, according to the Ministry of Home Affairs (MHA). Three zones are indicated by color-coding on the portal: green, yellow, and red. Drone activities are allowed in Green Zones as long as the drone has a license. Drone activities are permitted only in designated regions, known as "yellow zones," with approval from all relevant authorities. The local law enforcement will need to log authorization to fly a drone into the gateway. Drone activity is specifically forbidden in red zones. These are the institutions that fall within the MHA's purview. The policy entails features to restrict the use of unauthorized drones by incorporation of Radio frequency Identification (RFID) tags and Global system for mobile communications GSM sim card mandatory. Unmanned Aerial Vehicles (UAVs) provide law enforcement agencies surveillance capabilities that are not possible with existing technology. The Visual Line of Sight limitation that is placed on drones controlled by civilians does not apply to law enforcement agencies or the government in India, as it does not in many other nations. Instead than being utilized for targeted surveillance, UAVs are more likely to be employed for bulk monitoring.[5]



On the basis of literature survey the percentage use of drone in various sectors from Forensic perspective is portrayed below in figure 1.

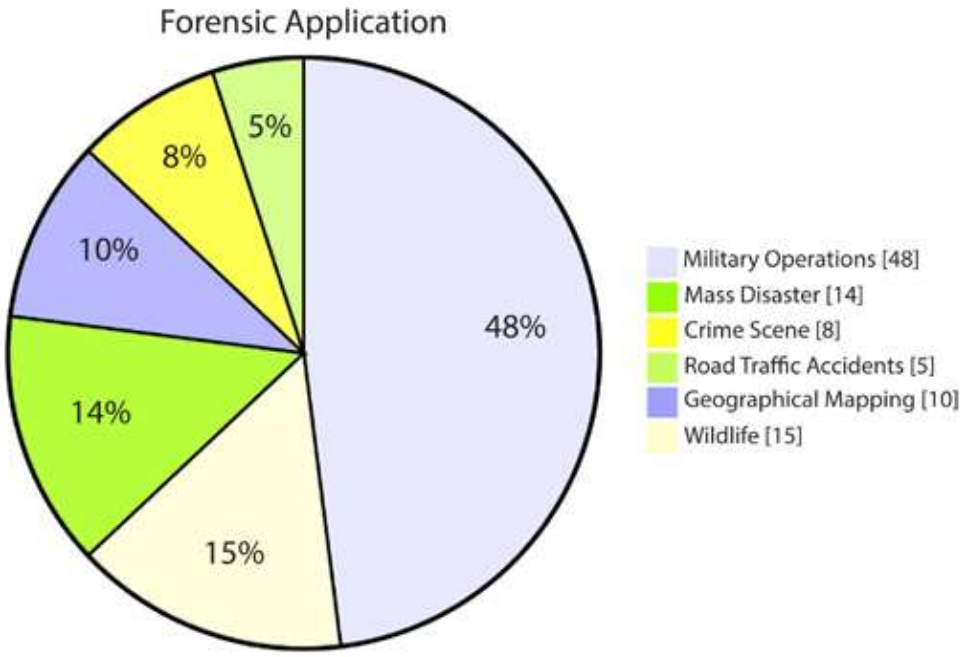


Figure 1: Drones and their forensic Applications

Drone Technology & Architecture

The UAV is an articulation that can fly without pilot; that is, an airframe and a computer framework which consolidates sensors, GPS, servos and central processors.[6] An UAV system comprises of various modules given in figure 2 that works in coordination to give desired output.

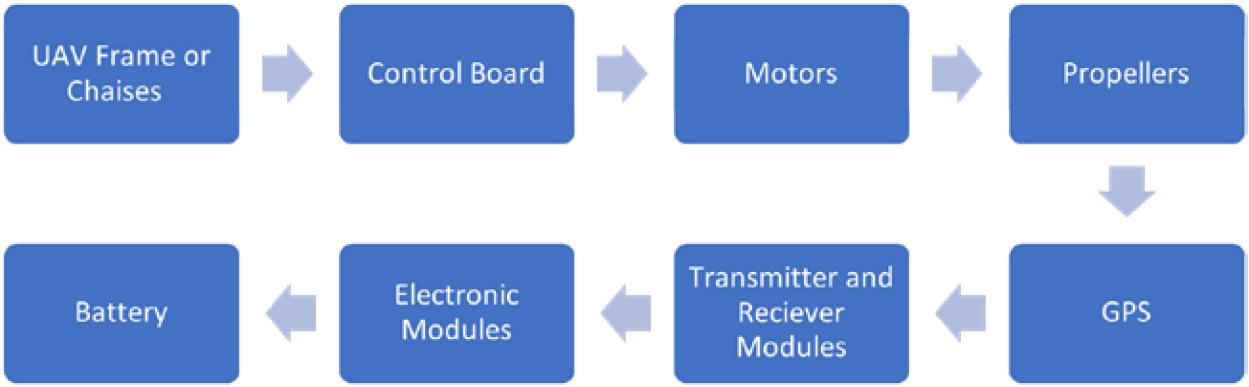


Figure 2: Parts of UAV[10]

The drone architecture is illustrated below showing its functionalities on the basis of autonomous flight capabilities.[7,8]

- **Remote Pilot Control**: It is completely controlled by operator using remote and it is known as operator based automation.
- **Remote Supervised control**: It provides robust automated control it empowers drones to launch itself and complete a task independently with partial human intervention.
- **Full autonomous control**: These are capable of making all required decision and logical interpretation, do not require human intervention.

Furthermore, the drones are also categorized on the basis of architectural framework given in figure 3 such as:

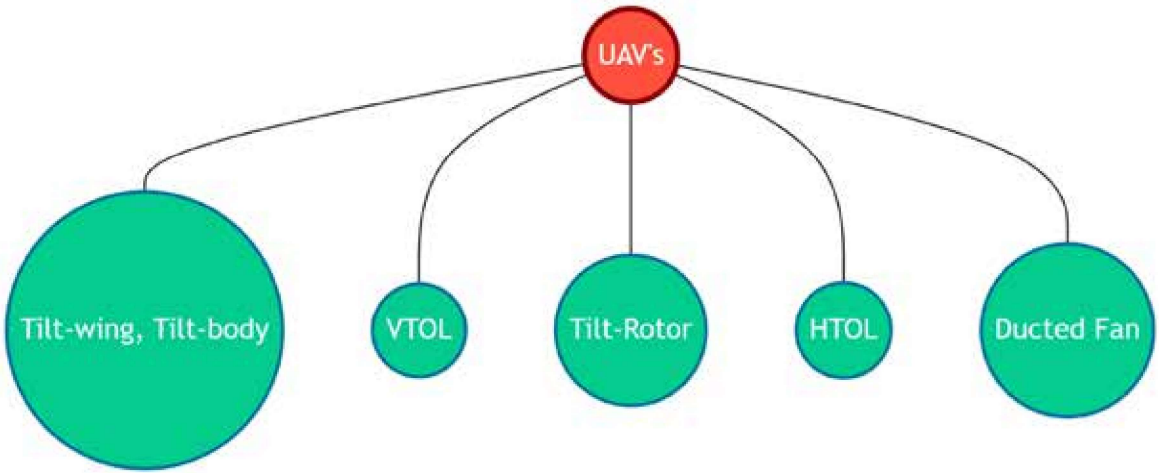


Figure 3: Types of drones on the basis of its operation

HTOL (horizontal take off landing): These drones carries fixed wings and the landing gears are same as of regular aeroplane. It requires runway for landing and take-off. Due to its fixed wings such drones exhibit better flight efficiency and operational ranges compared to VTOL (Vertical take-off and landing drones) drones. Its aerodynamics allows gliding which gives improved energy efficiency and longer flight times. It is well suited for operations like mapping, surveying and surveillance over larger areas. Moreover, these drones can sustain harsh weather conditions particularly windy environments. Hence, it becomes a good choice in scenario where efficiency, speed, and payload capacity is required.

VTOL (vertical takeoff landing): It uses rotors to get moving forward and landing or taking off does not need runway area. Vertical Take-off and Landing (VTOL) drones are a type of unmanned aerial vehicle that is made for flight purposes that are more flexible. Different from regular fixed-wing drone, VTOL drones have capability to go up or down in vertical direction which gets rid of needing the runway to operate. This means they work with efficiency in smaller places. These drones are significantly used for city monitoring, response to disasters or inspecting infrastructure. VTOL drones have features to hover so they can stay in one spot while flying, which is helpful for jobs that need exact motion in air or to observe from point. They can be used fast, and simple to handle, and switch between going up and flying forward without complexity. This is why they are used a lot in various areas, emergency services, and agriculture and also for aerial photography. With unique design it offers multiple rotors and wing options making them valuable tools in diverse mission profiles and environments.

Hybrid model (tilt-wing, tilt-rotor, tilt body, and ducted fan): Essentially, the drone merges the features of both VTOL and HTOL drone types and is capable of maintaining a vertical takeoff and landing before executing horizontal flight with the assistance of several tilt shift rotors and wings. Innovative UAV (unmanned aerial vehicle) configurations such as tilt-wing, tilt-rotor, tilt-body, and ducted fan drones characterize the flexibility and the extension of the capabilities of the drone technology by the aerial vehicles. The wings of a tilt-wing drone can be turned to change the flight mode from vertical to horizontal and vice versa, thus, allowing the use of the same drone for different purposes while still maintaining the efficiency of the fixed-wing flight. Tilt-rotor drones use rotors that can be adjusted, so they can take off and land vertically like a helicopter, and pitch forward for a faster, more energy-efficient forward flight. The flexibility of the folding fuselage in the tilt-body drone that can pivot thus letting a smooth transit to or from vertical to horizontal flight is what sets this model apart from other ones. Combining the benefits of both fixed-wing and multirotor makes it possible through this concept. The adaptability that these cutting-edge designs offer is a solution for the problem of limited spaces, longer-range missions, and the need for very accurate aerial maneuvering, thus, they are perfect in the drone technology market that is constantly changing.[8,9]

Forensic Applications of Drones across Domains

1. Drone: A unique troop in military forensics

UAV's can be best utilized for military operations, especially for gaining information input, surveillance and perform combat task with precision. They offer various advantages over traditional manned aircraft and ground-based systems as it provides operational effectiveness and reduces the amount of risk in modern battlefield. Some of the key uses of drones in the military.[13] Unmanned aerial vehicles are significantly deployed for Intelligence, surveillance and reconnaissance (ISR) objectives.[11,13] Fitted with imaging devices, sensors, and other state-of-the-art technologies, armed drones are capable of fetching fresh intelligence, keeping track of the enemy's maneuvers, and observing from above a large region without the taking of human lives. It is through them that the military obtains the most accurate information about the situation happening on the ground and so can issue orders with certainty. The reconnaissance depicted in figure 4 can be both active and passive.[7]

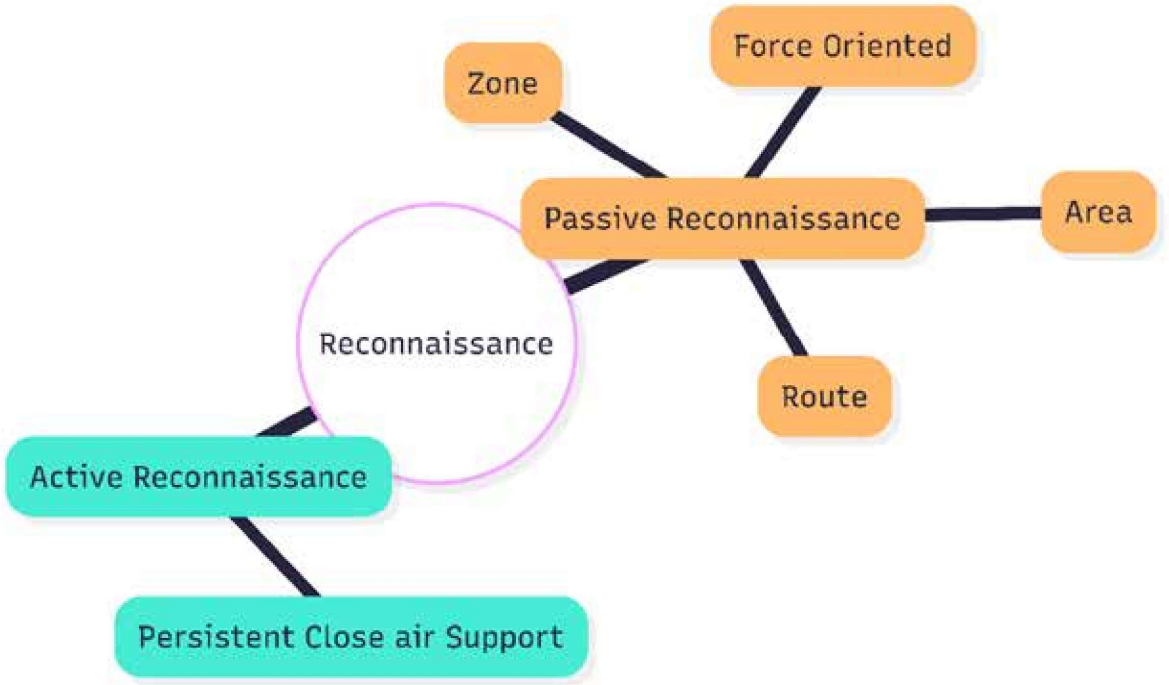


Figure 4: Types of Reconnaissance

Target Acquisition and Targeting: Drones having sophisticated targeting system are able to locate and follow targets that are either on the ground or in the air. In this way, they can send live video streams and target locations to the ground personnel or to other aircraft, thus, enhancing the accuracy and lessening the collateral damage resulting from the airstrikes or artillery fire.[12]

Strike Operations: Unmanned aerial vehicles (UAVs) like the Predator and Reaper, which are equipped with weapons, can hold and release precision-guided munitions.[12] They also have the capability to carry out the targeted elimination of the high-value enemy targets, e.g., enemy combatants, vehicles, command centers, or weapons caches. These drones provide long endurance, continuous surveillance, and exact strike abilities, which make them very powerful instruments in the fight against terrorism.

Force Protection: Drones are instrumental in force protection, for instance, they can provide early warning and detection of a possible threat. They can also scout through the areas assigned to them, figure out the hostilities and inform the army units of the power with the arrival of the enemy forces which in turn helps to secure army camps as well as soldiers.

Electronic warfare: The drones with electronic warfare systems onboard have the capability to sever or completely nullify the enemy's

communication, radar, and other electronic systems. Such drones can jam the enemy's radio signals, listen in on communication, or even gather information about the enemy's electronic capabilities which in turn gives a great leverage in electronic warfare operations.[14]

Logistics and Resupply-Drones are also available for use as logistic tools in carrying out tasks like delivering the necessary supplies, ammunition, or first aid to the areas which are secluded or hard to reach. They are a quicker and more effective means of transport as compared to traditional methods which are still used in the delivery of goods and thus the possibility of the resupply of the ground forces being attacked is almost eliminated.

Battlefield Damage Assessment-The military drones on the other hand, can be commanded to survey the damage that was done after a bombing or a military operation and later on collect the data for further analysis. Additionally, they can inspect the ground, spot the dangers, and at the same time, they can be a source of information critical in the preparation of future missions.

2. *Drone: A searching soul in DVI (Disaster Victim Identification)*

A mass disaster may be a causality that is natural, manmade, or both. The nature of the disaster determines the differences in the examination and the investigation of such disaster. Such a difference is evident in the case of train accidents/ aircraft classified as a closed system. Further differential analysis is performed for open systems, such as cyclones, earthquakes, tsunamis, etc.[15] Various law enforcement agencies are implementing rigorous measures to rescue victims, document the situation, and conduct investigations in response to such natural or manmade causality. For the same purpose, they are overcoming various challenges by performing more procedures simultaneously. Among these challenges are the approach to the disaster site and management of logistics. The use of drones is helping to record, locate, and rebuild the whole area of the calamity with the implanted technologies such as the sensors (thermal imaging & LIDAAR), GPS and real-time monitoring cameras.[16] By utilizing highly sophisticated imaging technologies, drones are able to swiftly perform aerial assessments, and provide up-to-date information of the areas affected by the calamity. In addition to this, these machines can also be used to quickly scan a large area in the least accessible parts, where they can consequently pinpoint the locations where the victims have been trapped and rescue is required. Drones equipped with thermal imaging cameras are ideal in search and rescue operations as they can help locate the heat signatures of the survivors in the regions which are both inaccessible and where traditional methods cannot be utilized. Moreover, these unmanned aerial vehicles help generate accurate maps and build 3D models to be able to support the planning process and also to be used in the risk assessment. Drones may also be employed as communications relays in this connection. They permit different rescue teams to coordinate among themselves when the area has a broken-down infrastructure. Their contribution does not stop there to simplify forensic methods by obtaining the needed information for reconstructing the events that led to the disaster and supplying the ways for victim identification. In addition, they may be able to keep an eye on disaster sites indefinitely, thus guaranteeing the safety of the rescue personnel and making it possible for them to be informed of any changes in the situation in a timely manner. Given their numerous functions, drones are very much a part of the comprehensive approach to disaster management, and without them, it would be very difficult for such a quick, precise, and comprehensive identification and recovery of victims as well as support in such endeavors to be realized.

3. *Wildlife & Forensic Ecology*

As per the wildlife protection act, it is quite clear that the conservation of red species animals has become a matter of extreme urgency. It is quite obvious that drones are being utilized in the conservation of wildlife, a fact which has raised the exposure of conservation with such technologies as drones etc. Conservation of wildlife will hardly be possible without the use of real-time monitoring across the various data sets such as wildlife population size, habitat degradation, species, animal tracking etc.

This is a modern tool that is very efficient and quite economical. So, the dependence on getting geotag images is becoming more and more important than satellite imaging. Consequently, it is playing the role of a very

detailed instrument for investigation as well as wildlife conservation.[3] Use of drones in conservation is a tech-based activity that helps in data gathering, surveillance, and forensic analysis, thus, it is a measure for the protection of endangered species and their ecosystems. The conservative forensic method includes the use of drones for identifying the following intentions:

- **Monitoring and Surveillance:** The use of drones fitted with sophisticated cameras and sensors allows the observation of the natural habitats of the animals as well as following the movements of the endangered species. This surveillance tool gives the power to the conservationists to count the populations, study the behaviors, and locate the possible threats of the ecosystem.
- **Anti-Poaching Operations:** The use of drones is very essential in the identification and prevention of the illegal activities such as poaching. By employing features such as thermal imaging and infrared cameras, the surveillance of large areas can be done by these unmanned aerial vehicles, the detection of poachers is possible and they can also send the information to the law enforcement and conservation teams which can take immediate intervention.
- **Habitat Mapping and Assessment:** The use of drones also assists in mapping and assessing the habitats of the wildlife and by doing so they provide a lot of detailed information about the land, the plants, and even the weather. This information is very helpful in making the right decisions for the conservation and in the implementation of strategies aimed at saving the habitats that are in danger.
- **Wildlife Census and Population Estimation:** With the help of drones it is possible to do the monitoring of the wildlife in such a way that they are not disturbed resulting in accurate censuses and population estimations without the need for direct contact with the animals. This data is of great help to conservationists in understanding the population trends and thus they are able to implement the right conservation measures.
- **Forensic Analysis of Wildlife Crimes:** The use of drones in the gathering of evidence is the best option when it comes to cases of wildlife crimes such as illegal hunting or trafficking. They shoot high-resolution pictures and videos which help the forensic experts in their lab work as they reconstruct the crime scenes and identify the culprits. The given evidence is very instrumental in court actions against individuals who are found to be involved in wildlife crimes.
- **Research and Data Collection:** It is a great tool in research work as it can collect information about animal behavior, migration patterns, and ecological interactions This data contributes to the understanding of the ecosystems, thus, it supports more informed conservation practices.

The central idea of wildlife management revolves around numerous key factors as mentioned in figure

Figure 5: Elements of Wildlife

4. *Drone: A virtual investigating officer in crime scene*

Drones are trained for crime scene investigation by serving a tool as documenting, searching and reconstructing various incidents.[17] Furthermore, they also implicated with LIDAR, Laser scanning techniques for 3D model generation for portraying entire crime scene to court room.[18,19] Drones assistance in CSI not only adds in collection protocols of evidence

but it also replicates full proof monitoring and documenting procedures. Thus, it leads to maximum coverage area for investigation of any type of crime scene.[20]

5. *Drone: A map on road to investigate traffic accidents*

Many cases reported for road traffic accidents but still due to scars of investigation it could not lead to any judgement. Hence, leading to misinterpretations. An AI based model has been developed in conglomeration with cloud technology. This cloud technology enforces clod dots embedded in drones for capturing virtual dimensions of accident sites and portrays the same as georeferenced points for construction of models (3D) and their presentation in the court room. Furthermore, these models are also utilized for identifying, collecting various evidences such as tyre marks, skid marks, paint marks encountered in various crime scenes.[21-22]

6. *Drone: A special guest in underwater environment*

Surprisingly, Drones are used in various investigation procedures of underwater forensics. These drones are customized specifically for detection and facilitation of the investigations to be used for underwater causality/ search and seizure procedure. The detailed implications of such types of drones mentioned below:

Search and recovery: DRONAR (Drone + Sonar) are specially aided UAV's used for underwater detection and collection of submerged or merged deceased bodies,[23] vessels, artefactual heritage resources or evidences related to any criminal act. With the help of these drones in culmination with sonar waves the investigation officers can search and recover the assets/deceased bodies up to various depths which are inaccessible for human divers as shown in Figure 6 below.

Digital Imaging: Various technologies are being widely used to capture images in water. Fortunately, these technologies are enabling forensic expert to identify evidences and potential leads by capturing detailed images and video footage of underwater scenes with the help of high resolution cameras embedded in drones.[24]

Mapping and 3D Reconstruction technologies: A three-dimensional portray is reconstructed by utilizing drones specially aided with sensors and imaging technologies for mapping underwater environments, surveillance.[24]

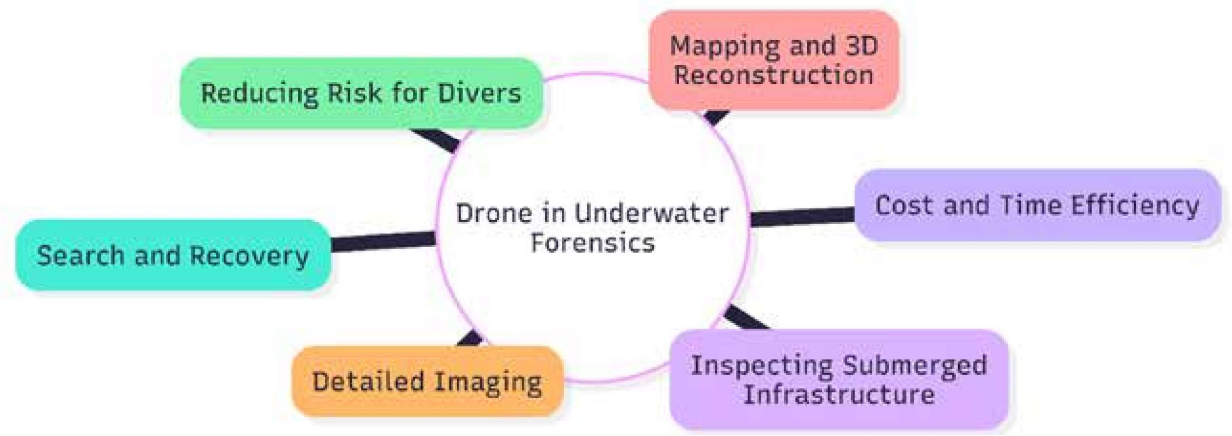


Figure 6: Application of Drones in Underwater Forensics

Forensic Analysis of Drones

The rapid development of drone technology has allowed them to be utilized in various sectors, that is, commercial, military, and personal, smoothly. Nevertheless, the rise in their count has led to the appearance of concerns related to security, privacy, and forensic investigations. Drone forensics, detailed investigation of digital drone data, has become a vital area to be devoted to solving problems resulting from this situation. This chapter is an introductory book about drone forensics with the inclusion of the main ideas, methods, problems, and future aspects. Drone

forensics is the work of finding, recording, safeguarding, examining, and recreating the data of the flight of an unmanned aerial vehicle (UAV) that is connected with an incident or a crime. It is a mixture of techniques from computer forensics, mobile forensics, and specially prepared software aimed at dealing with drone data features.[25,26] The extent of drone forensics is not only about hard data retrieval from the drone. It is also about the analysis of the data of the devices that are linked, for example, remote controllers, and the understanding of the operational environment, being the drone's flight paths, sensor data, as well as communication logs.[27,30]

1. Key Concepts in Drone Forensics

Data Sources in Drones

Drones are capable of recording a large amount of data both inside their memory and on an external storage device, like an SD card. The main sources of forensic data are:

1. **Flight Logs:** The logs illustrate the drone flight history in detail, GPS coordinates, altitude, and speed being some of the data, and the logs are usually time-stamped.[28]
2. **Sensor Data:** For example, the drone accelerometers, gyroscopes, and cameras could be considered sensors which produce a continuous stream of data during the drone flight.[26]
3. **Communication Logs:** Information exchanged between the drone and its remote-controller includes command sequences and telemetry data.[30]
4. **Media Files:** The drone's photos and videos can help establish the context and thus be used as a textual support.

2. Types of Evidence in Drone Forensics

Information recovered from drones may be divided into two main classes:

1. **Volatile data:** This refers to temporary data kept in the drone's memory, for example, running processes, and network connections. Volatile data is short-lived and therefore, it has to be collected very quickly in order to avoid it being lost.
2. **Non-volatile data:** This refers to permanent data that can be found on the internal memory of the drone or on the external storage devices, for example, flight logs and media files. Non-volatile data is more stable and can be analyze for a longer period of time.

Forensic Frameworks for Drone Analysis

Several different frameworks have been put forward to facilitate the forensic investigation of drones. These frameworks usually include the following four stages:

1. **Preparation:** Gathering all necessary information about the drone is part of this stage. This includes identifying the model and noting down the hardware and software specifications. Also, the examination of the legal and regulatory aspects governing the drone's use must be done.
2. **Data Collection:** This stage is about the extraction of data from the drone along with any devices that are associated with it. It is imperative that the data collection process is done in a forensically sound manner so that the integrity of the evidence is not compromised.
3. **Analysis:** Here the focus is on going through the data that was collected in order to find the most relevant pieces of evidence and the sequence of the events. In this stage, different tools and techniques can be used, and one such option is machine learning algorithms.
4. **Documentation:** In this stage, the results obtained are recorded along with the methods, the evidence, and the conclusions. Correct documentation plays a vital role in legal proceedings and can also be of use in the future.[29,32,33]

3. Forensic Methods and Techniques

Data Extraction and Analysis

In general, the extraction and analysis of data from drones is a multi-step process which includes the following:

1. **Physical Extraction:** This is the part where one physically opens the drone to access its internal memory and external storage devices with the aim of getting hold of the raw data. In case the data are encrypted or in a proprietary format, one may need special tools, for example, drone data parsers, to process the data.

2. **Logical Extraction:** Here, the emphasis is put on the file system of the drone from which data are extracted such as logs, configuration files, and media files. Logical extraction is generally a lighter intervention than physical extraction and hence can be done by means of forensic software tools.
3. **Data Parsing and Reconstruction:** This is the stage when the extracted data are understood and used to trace back the drone's activities. It may involve the usage of figures to show the route taken by the drone, analysing the data collected by the sensors, and checking the communication logs to see when the drone was flown[37]

4. Machine Learning and AI in Drone Forensics

As the data obtained from drones has become more complex, the use of machine learning and AI-based techniques has been increasingly favored in forensic analysis. These techniques may be implemented for:

1. **Anomaly Detection:** Machine learning algorithms can learn from data to figure out untypical patterns in drone data, for example, sudden changes in the flight paths or unusual communication activity.[34]
2. **Object Detection:** Methods of deep learning, like YOLO and SSD, might be employed to locate and identify the objects in the pictures and videos captured by the drone, thus, facilitating the identification of the new sources of the crime.
3. **Timeline Analysis:** The use of machine learning in studying drone timelines allows analysts to spot abnormalities and create the timeline of the incident by deriving the logical flow of events.

5. Digital Twin Technology in Drone Forensics

Digital twin technology has emerged as a promising tool in drone forensics. A digital twin is a virtual replica of the drone that can be used to simulate its behaviour and analyze its data. This technology can be particularly useful in reconstructing the circumstances of a drone accident or incident.[31]

Challenges in Drone Forensics

Despite the improvements in drone forensics, there are still a few problems that have been listed as follows:

1. The fast technological evolution of drone has resulted in a great number of different kinds of hardware and software configurations which, in turn, makes it very difficult to create standardized forensic tools and methods.[27]
2. In order to hinder the work of forensic experts, encrypted and anti-forensic methods might be used in the data of drones which, in their turn, can cause difficulties in the forensic analysis.[36]
3. The rules and regulations related to drone use and forensic analysis, which form the legal and regulatory framework, differ from one jurisdiction to another, thus, creating problems for investigators.[32,33]

6. Tools and Techniques in Drone Forensics

Forensic Tools for Drone Analysis: The forensic analysis of drones has been facilitated by the introduction of several tools. These tools could be divided into two categories broadly:

1. **Proprietary Tools:** These are highly specialized instruments created by drone developers, for instance, DJI's Dat Con and CSVView, which are aimed at parsing and analyzing data from particular drone models.
2. **Open-Source Tools:** These are instruments created by the forensic community to accommodate various drone data formats and models. The examples of such tools are those that facilitate the extraction and analysis of flight logs and sensor data.[38]

Table 1: Comparison of Drone Forensic Tools

Tool Name	Key Features	Supported Drones
DatCon	Flight log parsing, data visualization	DJI drones
CSVView	CSV file analysis, data export	DJI drones[38]
LLaVAFor	AI-powered analysis, anomaly detection	General drones[39]

7. Future Directions in Drone Forensics

Standardized Forensic Frameworks

It is a must to have the development of standardized forensic frameworks for drone

forensic investigations that will be consistent and reliable in. Moreover, these frameworks should be universal for different drone models and their operational environments.

Integration of AI and Machine Learning

By employing AI and machine learning in drone forensics, the forensic analysis will be very much proper in terms of its accuracy and speed. Besides, data analysis can be fully automated, anomalies can be detected, and complicated events can be reconstructed by these technologies without human intervention.[38]

International Collaboration and Regulatory Frameworks

The use of drones is worldwide, so there must be cooperation among countries and the creation of standard regulatory frameworks. Such a partnership is very important to solve the legal and regulatory problems that investigative officers encounter.[32,33]

CONCLUSION

In a nutshell, the review portrays the benefits of UAV's in forensic sciences for various purposes such as in military forensics, underwater forensics, mass disaster cases and wildlife forensics etc. The drone utilization not only limits in forensics but it also propagates to another branch of science and technology. It is found that drone serves as a model of proactive forensics which aids in forensic criminal investigations. Starting from crime scene investigation till judgement it plays pivotal role in maintaining and documenting the chain of custody as a real time monitoring technique. It also concludes that the utilization of this tool not only helps in investigation but it also prompts in preventing crime, technical management and logistics management. Therefore, Drones are a pivotal equipment for the forensic department. Drone forensics is an extensively varied and fast-moving discipline which helps greatly in overcoming the problems which are raised by the wrongful use of drones. The discipline has been mixed with the conventional forensic methods and instead of the old ways, they use the new ways and means, e.g. machine learning and digital twin technology, to breach the incidents related to drones. Without a doubt there are some difficulties, however, the incessant evolution of standardized frameworks, instruments, and techniques will be very effective in solving the cases by drone forensic investigations. Moreover, when drone technology is getting better and better, the issue of drone forensics will be a matter of utmost importance, thus the area will be very much open for further research and development.

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