Enhancing Crime Scene Investigation with Drone Technology: The Potential of Unmanned Aerial Vehicles in Streamlining Evidence Collection and Analysis

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Abstract: The utilization of drones by military and law enforcement entities have become widespread for tasks such as monitoring, guarding borders, and conducting stealth operations. They are now used for various purposes such as monitoring and guarding borders, conducting stealth operations, and even in the field of forensics. In recent times, the utilization of drones in forensics has seen a significant increase, with the use of drones for tele-forensics and videography being some of the most prominent applications. One of the critical aspects of crime scene investigation is crime scene documentation. This process involves collecting all the data available at the scene and preserving it for future reference. Crime scenes are usually revisited if the need arises, and the collected data is used for analysis. However, the process of managing crime scenes and investigations is time-consuming and can be vulnerable to tampering and disturbance. The paper proposes using advanced photogrammetry techniques along with simultaneous localization and mapping to reconstruct crime scenes. This approach, when combined with the latest advancements in drone technology, can result in detailed 3D models of crime scenes and accident sites, enabling investigators to revisit the scene and analyze it from multiple angles virtually; and aid in providing evidence in court. This will guarantee that the evidence is preserved in its original condition long after the on-scene inquiry is over. This information is vital since it could take weeks or even months for an investigator to revisit a scene and discover new, significant evidence. Drone-based photogrammetry offers many advantages over traditional methods of data collection, including increased accuracy, speed, and safety.

Key Words: Drone, Photogrammetry, Forensics, Simultaneous localization and mapping, Accident reconstruction

I. Introduction

Drones have been widely used by the military and law enforcement agencies for various purposes such as surveillance, border patrol, and covert operations. The management of crime scenes and investigations is a complex and time-consuming process that is susceptible to contamination and manipulation. To solve these issues at the crime scene, a drone, an unmanned aerial vehicle with functional diversity, can be used. Drone-based photogrammetry, using tools such as RGB cameras, LiDAR, and Ground Control Points (GCPs), has proven to be much more precise and accurate than traditional methods of handwritten notes. These advanced algorithms have
enabled the creation of detailed 3D models of crime scenes, allowing investigators to revisit the scene and analyze it from multiple angles virtually. The use of drones has also allowed for the collection of a wide range of visual data including images, video, and thermal imagery, which can be used to accurately reconstruct events and determine the cause of an accident. With its speed and accuracy, drone-based data collection has become a valuable tool in forensic investigations and accident reconstructions, helping to streamline the process of gathering and analyzing evidence, leading to more effective and efficient investigations. This research paper will examine the potential of using drone-based photogrammetry as a tool for forensics, exploring how this technology can streamline the process of gathering and analyzing evidence and lead to more effective and efficient investigations.[2][3][4]

II. Background Information

2.1 Photogrammetry

Photogrammetry is the science of obtaining reliable and accurate measurements from photographs. It involves taking pictures of a scene to learn more about the objects' spatial and physical characteristics. A wide range of cameras and platforms, such as satellites, mounted cameras aboard airplanes, and ground-based cameras, can be used to acquire photographs. The information about the objects in the scene is then extracted from the images using specialized software. With the use of this data, a scene can be represented digitally in the form of a 3D model, orthophotos, and digital elevation models.[5]

Compared to conventional measurement methods, photogrammetry has several benefits. It is relatively inexpensive, fast, and flexible, making it an attractive option for many applications. Additionally, photogrammetry is non-contact and non-destructive, which means that the items being measured are not affected or harmed.

2.2 Structure from motion (SfM)

SfM is a powerful technique in photogrammetry that uses overlapping 2D photos to generate 3D models. It has gained popularity in recent years due to its ability to manage collections of various and randomly arranged photos without having prior knowledge of camera properties. As a result, precise homogeneity in the camera placements, calibrations, and overlapping pictures is not necessary to produce photogrammetric models.[6]

SfM is distinct from traditional photogrammetry in several aspects. First, SfM's image-matching technique is perfect for handling pictures taken from unsteady or unstable platforms since it enables the automated detection of features in various scales, viewing angles, and orientations. Second, SfM can complete the equation for the method without knowing the positions of the cameras or the ground control points. This enables automatic camera calibration resolution or enhancement during the processing step.[7]

SfM is a versatile and flexible technique that has revolutionized the field of photogrammetry. Its ability to handle collections of heterogeneous and unordered photos, produce accurate and high-quality outputs, and resolve camera calibration makes it a popular choice for photogrammetric modeling. Whether it's used in close-range photogrammetry, drone-based photography, or other applications, SfM continues to play a crucial role in the field of photogrammetry.

2.3 SLAM

SLAM algorithms assess the camera's pose and create a map of the environment using stereo cameras and other sensors. The algorithms use real-time visual data from the cameras and other sensors to estimate the movements of the camera and the environment's structure. The generated map can be used for navigation, mapping, and other purposes, including augmented reality and self-driving cars.[8][9]

A stereo camera is a type of camera that contains two lenses with a small baseline between them. By using this baseline, the stereo camera can take two photos at once and determine the depth of objects in the scene. The stereo camera can calculate the separation between the camera and the scene's objects by comparing the differences
between the two images. A 3D model of the environment can be made using this data and used for navigation, mapping, and other applications.[10][11]

Stereo cameras are commonly used in close-range photogrammetry and SLAM applications. They provide a cost-effective and efficient way to capture 3D information, which is useful for applications that require real-time depth information. The use of stereo cameras in SLAM algorithms can improve the accuracy and robustness of the mapping and localization, especially in environments with low texture or low light conditions.[11]

2.4 Forensic photogrammetry and history

The use of photogrammetry in forensic science has a long history, dating back to the early 20th century. At first, photogrammetry was used to capture crime scenes in 2D images, but with the advent of technology and the development of new photogrammetric methods, the field has expanded to include 3D modeling.[12] With the introduction of UAVs (Unmanned Aerial Vehicles) and advances in imaging technology, UAV photogrammetry has become a crucial tool for forensic investigations.

UAV photogrammetry allows for quick and efficient mapping of crime scenes, providing investigators with an overview of the scene and determining entry and exit points before investigators physically reach the scene. This is especially useful in difficult-to-access locations, such as high-rise buildings or remote locations, as small and lightweight UAVs can easily capture close-up images without disturbing the evidence. In recent years, UAV photogrammetry has been tested in the forensic context and is capable of producing high-quality images and accurate large-scale 3D models of forensic scenes.[13][14]

However, despite its benefits, UAV photogrammetry is not without its limitations. The accuracy of UAV photogrammetry is dependent on the accuracy of the GPS survey used to scale and geo-reference the data. In indoor surveys, this can result in less accurate results compared to laser scanning. To overcome this limitation, the integration of both techniques is necessary to produce accurate and complete models.[3][15]

III. Scope of the study

The scope of study for this research paper is to examine the current use of drones in crime scene investigation and to evaluate their impact on evidence collection and analysis. The study will focus on advanced photogrammetry algorithms in enhancing crime scene investigation. This paper aims to explicate a novel approach to autonomous crime scene reconstruction to help preserve the crime scene and to make the documentation better.

IV. Methodology

According to previous research, the major problems faced when deploying drones in the field are the requirement of a drone pilot, the unavailability of GPS in indoor surveys, and obstacle avoidance. With the current advancements in hardware and software, we can now incorporate techniques that do not require any drone specialists and can solve a multitude of problems. To allow the drone to move autonomously we deployed a version of SLAM, along with a stereo camera; and for 3D mapping, we deployed a photogrammetry pipeline.

4.1 Data acquisition

A crime scene can present itself in two possible ways: either the crime scene is situated in an (i) outdoor or (ii) indoor setting. There would typically be a need for a drone pilot; however, this requirement can be overridden by autonomous deployment or flight plan operations. Due to the lack of GPS in a small space within a building, flight plan operations cannot be deployed. Autonomous flight options such as Simultaneous Localization and Mapping (SLAM) have proven to be suitable for deployment in both of the conditions highlighted above.
In this scenario, we have employed the use of ORB-SLAM[8], on the drone for data collection. ORB-SLAM is a versatile and accurate SLAM solution for Monocular, Stereo, and RGB-D cameras. It can compute in real-time the camera trajectory and a sparse 3D reconstruction of the scene in a wide variety of environments. It has been proven to be compatible with both stereo and monocular cameras to track the drone's position and build a map of the environment in real time. The algorithm comprises several modules, which include:

1. Feature Detection and Description: ORB features have been extracted from the image, and their position and orientation have been computed.
2. Tracking: The ORB features have been used to track the drone's motion and estimate its position and orientation.
3. Local Mapping: The algorithm has built a map of the environment using the ORB features and the drone's motion estimates.
4. Loop Closing: ORB-SLAM has used a loop-closing mechanism that allows for long-term mapping and relocalization. The algorithm can detect when the drone has returned to a previously visited location, and it can correct for any accumulated errors in the map.
5. Bundle Adjustment: ORB-SLAM has used bundle adjustment to optimize the camera poses and 3D points of the map.

One of the benefits of ORB-SLAM is that it can run on a standard CPU and does not require any specialized hardware. It also supports wide-baseline stereo, which allows the algorithm to handle large changes in viewpoint. This makes ORB-SLAM a suitable algorithm for use on drones, which often have limited computational resources and are capable of rapid movement. ORB-SLAM has been utilized for various applications such as indoor and outdoor mapping, autonomous navigation, and 3D reconstruction. It is also a good solution for applications where the environment is not known in advance, and it can be used in situations where GPS signals are not available.

Although monocular SLAM is possible, it suffers from a particular disadvantage, the camera cannot estimate the absolute scale, and hence a scale drift phenomenon is introduced. Keeping this in mind, we used a custom-made stereo camera, made using the following components:

Table 1: Components used to create a stereo camera

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry pi 0</td>
<td>2</td>
</tr>
<tr>
<td>Pi camera</td>
<td>2</td>
</tr>
</tbody>
</table>

The cameras are calibrated using a Python script, and the camera streams are then stereo rectified to generate a standardized output.
4.2 Data processing

While SLAM helps the drone to maneuver through an arduous environment, using the cameras we can collect images of the area of interest. These images are then processed to create 3D models, maps, and ortho mosaics that can be used for various applications, including forensic investigations.

![Photogrammetry pipeline](image)

The photogrammetry pipeline deployed includes the following steps:

1. **Image Alignment**: The first step in the photogrammetry pipeline is to align the images to correct for any camera movement or distortion. This is done using automated image alignment algorithms that match the features in the images and estimate the camera poses.
2. **Feature Detection and Description**: The next step is to detect and describe the features in the images, such as corners and edges. This is done using feature detection algorithms, such as SIFT or ORB, that extract key points and descriptors from the images.
3. **Feature Matching**: The feature descriptors are then matched between the images to determine the correspondences between the key points. This is used to estimate the relative camera poses and triangulate the 3D points in the scene.
4. **Dense Reconstruction**: After the relative camera poses have been estimated, the 3D points in the scene can be reconstructed using dense reconstruction algorithms, such as Structure from Motion (SfM) or Multi-View Stereo (MVS). This involves estimating the depth of the points in the scene using information from multiple images and creating a 3D point cloud.
5. **Mesh Generation**: The 3D point cloud can then be used to generate a 3D mesh that represents the surface of the objects in the scene. This is done by fitting a surface to the 3D points and creating a triangle mesh that approximates the surface.
6. **Texture Mapping**: The 3D mesh can then be textured using the images to provide a more detailed and accurate representation of the scene. This involves projecting the images onto the mesh and using them to create a texture map that represents the color and texture of the scene.
7. **Orthomosaic Generation**: The final step in the photogrammetry pipeline is to generate an orthomosaic, which is a composite image that combines multiple images into a single, large, rectified image. The orthomosaic is generated by projecting the images onto a common coordinate system and mosaicking them together.

In forensic investigations, drone-based photogrammetry can be used to document crime scenes, accidents, and other incidents. The high-resolution images and 3D models generated by photogrammetry can be used to support investigation and analysis, as well as provide evidence in court. Photogrammetry can also be used to create accurate and detailed maps of crime scenes, which can be used to help plan and execute investigations.[12]

A drone-based photogrammetry is a powerful tool for forensic investigation, offering a fast and efficient way to collect, process, and analyze data. The use of drones allows investigators to cover large areas quickly and accurately, while the photogrammetry pipeline provides a streamlined and efficient way to extract valuable information from the acquired images.
During photogrammetry, image features are converted to a point cloud which is similar to one created during SLAM’s “Local Mapping” step. We can incorporate SLAM’s point cloud within the photogrammetry pipeline, to increase the density of the overall point cloud, allowing us to maximize the usage of our resources.[16]

V. Results and analysis

Using the pipelines described above, we were able to test the systems in a closed room. The output generated by the ORB-SLAM is a disparity map, as seen below.

![Fig 3: Disparity map(ORB-SLAM)](image)

The disparity map is a visual representation of the relative depth of objects in a scene. The algorithm uses feature-based stereo-visual odometry to estimate the camera's motion and construct a 3D map of the environment. The disparity map is created by calculating the difference between the positions of corresponding pixels in the left and right stereo images and encoding this difference as a grayscale image. The lighter pixels represent objects that are closer to the camera, while the darker pixels represent objects that are farther away. The disparity map is used to generate a more accurate and complete representation of the scene, which can be useful in various applications such as robotics, augmented reality, and autonomous navigation.

The process of generating a 3D map from photographs is a time-consuming job. The photos must overlap to generate a well-defined 3D map. This means that there is going to be a large volume of data, which largely also affects the time it takes to process the data. For this particular model, it took nearly 2 hours with a total of around 400 photos clicked. Apart from the volume of data, process duration also depends on the computational power of the machine.

![Fig 4: Photogrammetry output](image)

The photos are first compiled into a dense point cloud, with all its features mapped out in the 3D space. As seen in the above image, we can start to see the highlight of the structures in the room. Note that this is partly similar to what stereo-based SLAM generates(Fig 3, Fig 4). The further steps include meshing and texturing which provides a better definition of the output generated.
By taking a closer look, (Fig 5(a)) we can see that we were able to map out the written details on the wall, and overall it did quite a good work of representing the little details in the room. Although minute details have been highlighted to a great extent, photogrammetry failed miserably at certain places, mapping walls, and thin objects. Throughout the close-ups, we can see that the surfaces are bumpy, a reason for this to occur is that the surfaces do not have much texture, or the textures weren’t captured accurately. This also happens when the surface is glossy or reflects light, however, an easy fix for this problem is to manually apply surface correction to make the surface smooth. Secondly, in Fig 5(c) we can see that there are holes in the wall, a possible cause for this could be that the images were captured quite close to the wall, which might have led to a disparity in the calculated depth for the feature points. A necessary step that needs to be taken is to manually clean the generated output to make it of a higher quality. Although this process can also be automated by using post-processing techniques, like, interpolation, extrapolation, and smoothing.

After the processing is completed, the then-generated output is a high-quality 3D map that can be integrated with other technologies such as augmented reality to provide an immersive experience. With advancements in computer vision and machine learning, the process of generating 3D maps is becoming faster and more efficient, making it accessible for a wider range of applications.

VI. Conclusion

To deliver an unfazed decision and to maintain a high-quality mapping of evidence, there is a continuing need to enhance the current methodology and techniques of investigation due to the rise in crime and to streamline the process. Any contamination could reduce the evidence’s usefulness and the investigation’s scope.[17] The management of the crime scene and the investigation require a lot of educated staff and experts, take a lot of time, and are susceptible to manipulation. To solve these issues at the crime scene, a drone, an unmanned aerial vehicle with functional diversity, can be used. With the rampant development in the drone industry, it is a well-established scientific fact that artificial intelligence is more efficient in performing certain tasks in comparison to humans which also minimizes the stress and labor to human beings. The current research project provides a backbone for the usefulness of UAVs in accident reconstruction. Based on the obtained results, this project provides reasonable support for drone deployment as an aid to forensic analysis:

1. Drone-based photogrammetry can result in high-resolution images and 3D models that can be used to support investigation and analysis, as well as provide evidence in court; over more traditional methods of data collection.
2. Easily able to reach inaccessible locations or areas that would be dangerous for an investigator to access on foot or by using other types of vehicles; eliminates the risk of injury to the investigator posed by potential security threats in high-risk environments.
3. It provides the possibility of enabling investigators to virtually revisit the scene and analyze it from multiple angles, which can be helpful to reconstruct events and determine the cause of an accident accurately.
4. Streamlines the process of gathering and analyzing evidence and ultimately leading to more effective and efficient investigations.
While the benefits of using drones in forensic investigations are clear, there is a major obstacle that still needs to be overcome before this technology can be fully utilized in the field. As highlighted above, drones are a highly efficient option for preserving a crime scene. However to achieve it the drone has to have a low thrust, which can only be achieved when the drone is lightweight. A probable method of achieving it would be using swarm technology, which would also bring multiple other benefits. Overall, the use of drones in forensic investigations has the potential to revolutionize the way crime scenes are processed and analyzed. With the combination of advanced technology and human expertise, investigations can become faster, safer, and more accurate, leading to a more just and efficient justice system.[2]

References


