3D Indoor Crime Scene Reconstruction from Micro UAV Photogrammetry Technique

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ABSTRACT

The application of micro Unmanned Aerial Vehicles (UAVs) in photogrammetry, particularly within the realm of forensic investigation represents a relatively novel approach and has gained increased attention. By measuring the distances and positions of the scene's components, it is feasible to document and visualize the scene using the photographs that were taken for the purpose of assisting investigators. Capturing accurate crime scene data within a short time frame is always a challenge. Conventionally, photographs were used to document the scene, but the technical qualities of the photographs depended on the skill of the present forensic personnel. The use of 3-Dimensional (3D) photogrammetry enables the production of highly realistic and detailed 3D documentation of a given scene. As this technique involves capturing a series of photographs, it can be a time-consuming process. Therefore, this study aims to explore an alternative approach that enables the rapid acquisition of the scene while preserving the intricate details, thus ensuring efficiency without compromising the accuracy of the resulting documentation. The study employs a methodological approach wherein data are collected from a simulated crime scene situated within a confined and hard-to-reach area. The data collection is facilitated through the utilization of micro UAVs. The acquired data are then processed utilizing photogrammetry software, leading to the generation of a 3D model point cloud. The collected data will be subjected to a comparative analysis with data generated using a Terrestrial Laser Scanner (TLS) as a reference, alongside Vernier Calliper (VC) measurements. The findings indicate that the Root Mean Square Error (RMSE) of the integrated point clouds from TLS and micro UAVs compared to the conventional method is approximately ±0.217 cm. It can be deduced that the integration of data derived from micro UAVs and TLS in forensic photogrammetry within a confined crime scene is viable and yields a high-precision 3D model point cloud.

Keywords-forensics; close range photogrammetry; micro UAV; TLS; data integration

I. INTRODUCTION

During the recent years, the field of photogrammetry has seen a rise of interest in the use of Unmanned Aerial Vehicles (UAVs), despite that their first uses were for military purposes [1-2]. Over time, the legal system embraced the use of photographs as permissible evidence. Subsequently, in the 1950s, the advent of the videotape recorder further expanded the admissibility of visual evidence in court proceedings. As photogrammetry transitioned into the digital era, forensic photogrammetry began incorporating digital cameras as a pivotal investigation tool. In the context of court admissibility, the recreation of the scene necessitates a meticulous establishment of high-precision elements including the position, direction and perspective of key components within the scene [3]. The captured images facilitate comprehensive documentation and visualization of the scenes through precise measurements of the position and shapes of their major components. However, the scene reconstruction process demands a multitude of object measurements, which can be time-consuming, particularly in extensive areas. This challenge is further amplified when employing the conventional method, which is Digital Single-Lens Reflex (DSLR) cameras in forensics, potentially impacting the authenticity and integrity of the investigation as the presence of the investigator could temper the objects in the crime scene [4]. The use of 3D reconstruction of indoor crime scene analysis enables the comprehensive documentation of evidentiary elements such as mapping of blood splatter patterns, meticulous comparison of various murder weapon types, and potentially revolutionising data collection which enables visualising and simulating the sequence of events [5-10]. The reconstruction of indoor crime scenes can be facilitated by numerous technologies that are beyond photographs and handwritten notes. However, even with modern technologies, it is necessary to take into consideration the technical constraints, user-friendliness, cost, and time duration of data acquisition [11-12]. A recent study reported that leveraging on UAV technology will improve the effectiveness of crime investigation, facilitating access to otherwise inaccessible areas and expediting the retrieval of images [13-14]. However, in a constrained environment, a micro UAV has the advantage of being able to manoeuvre in tight spaces. A UAV is considered micro if it is palm-size and weighs less than two kilograms [15-16].

This study explores the usage of micro UAVs using the Close Range Photogrammetry (CRP) method to capture images of the indoor crime scene from various angles and heights. By using the Structure from Motion (SfM) technique available in selected photogrammetry software, the same feature points of 2D overlapping photos generate a 3D model. Data obtained from micro UAV and Terrestrial Laser Scanning (TLS) are processed, compared, and analyzed against measurements obtained from conventional tools such as the Vernier Calliper (VC), to determine the level of accuracy. The integrated point cloud data from Micro UAV and TLS were also analyzed. The data integration from both sensors should enhance the accuracy and provide completeness of the 3D model point cloud, thus minimizing the risk of missing data in the model.

II. METHODOLOGY

This study adopted a research methodology that consists of three phases: (a) Research Planning and Design, (b) Data Acquisition and Processing, and (c) Results and Discussion, as depicted in Figure 1.

A. Research Planning and Design

The simulated crime scene was set up close to Geospatial Imaging and Information Research Group (GI2RG), Block C05 in Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia. To increase the complexity of the access to the mock crime scene, it was set up on top of a 12ft container placed within a stairwell of a three-story building as depicted in Figure 2.

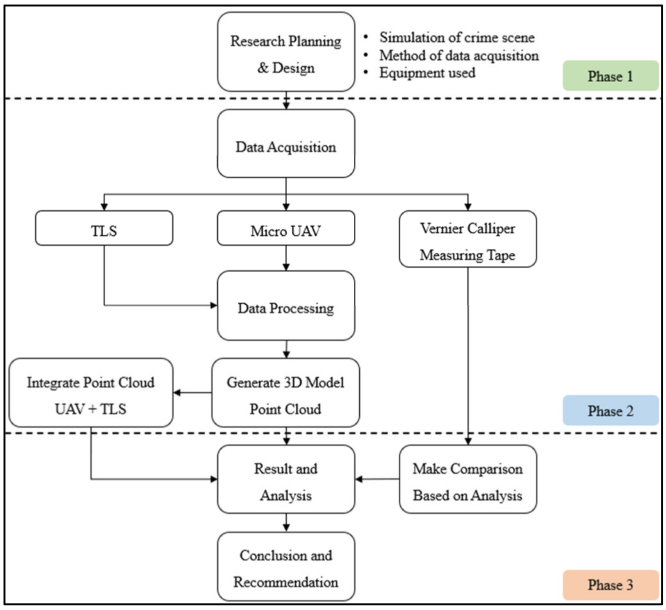


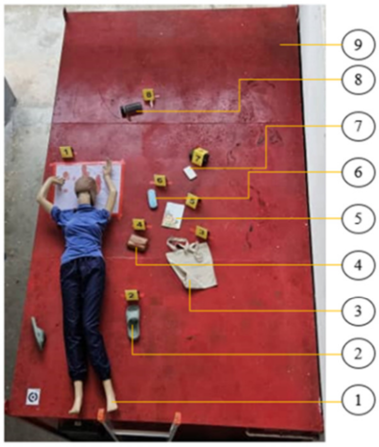
Fig. 1. Research methodology.

Fig. 2. Location of the mock crime scene.

Figure 3 shows the objects utilized to gauge the accuracy of the data extracted from the micro UAV, TLS, and the conventional measuring instrument. A total of seven objects were placed together with the victim as parts of the mock crime scene. The primary equipment used in this study as depicted in Figure 4 were: (a) DJI Mini 2 for the micro UAV, (b) Leica BLK360 for the TLS, (c) VC, and (d) measuring tape. The data generated from these tools were then processed using Agisoft MetaShape Professional and Cloud Compare photogrammetry software.

B. Data Acquisition and Processing

The placement of the TLS is crucial to ensure the coverage of the crime scene is complete. Since access to the scene was difficult primarily due to its height, the TLS was placed at 10 locations with differing heights and positions. The micro UAV was then deployed following a single grid pattern covering the entire crime scene. The time taken for the data acquisition using TLS and micro UAV was approximately 45 minutes to ensure full coverage of the crime scene. Figure 5 shows the approximate flight plan during the data acquisition.



No.	Items
1	Mannequin
2	Slippers
3	Tote Bag
4	Wallet
5	Book
6	Glass Case
7	Compact powder
8	Water Bottle
9	Cabin

Fig. 3. The distribution of the measured objects.

Fig. 4. Equipment used.

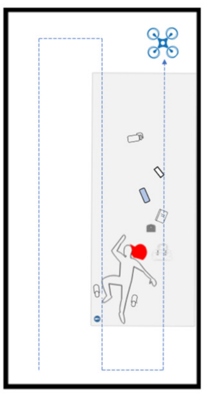


Fig. 5. Approximate flight path of data acquisition.

Upon completion of data acquisition involving TLS and micro UAV, the objects in the crime scene were then individually measured using a VC and a measuring tape. The data from the micro UAV were processed using the Structure from Motion (SfM) algorithm in Agisoft Metashape Professional software as depicted in [17] and the resulting output from the SfM was further processed as shown in Figure 6. Data from TLS on the other hand, were processed and filtered with Cloud Compare.

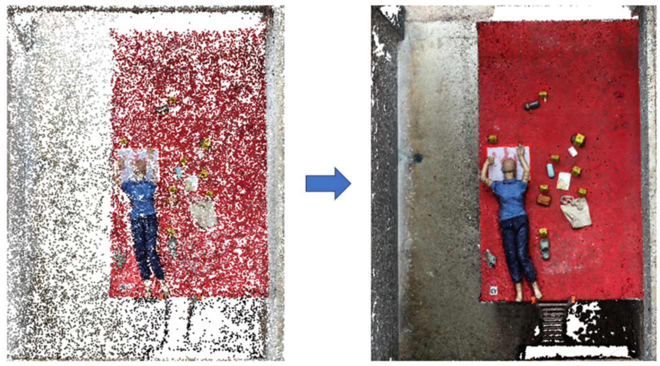


Fig. 6. The procedural flow of images from the micro UAV.

The latter is also used for point cloud integration from both sources using the Point Pair Picking (PPP) method. PPP is a manual approach of selecting common points between two-point cloud datasets. The selection of the common points had to be carried out manually due to the absence of a Ground Control Point (GCP) since the Global Positioning System (GPS) cannot be utilized in an indoor environment.

III. RESULTS AND DISCUSSION

The 3D model point cloud from Micro UAV generated from more than 100 images which produced 22.7-million-point clouds. Whilst for TLS, 54-million-point clouds were produced covering the crime scene and beyond, which were later filtered to focus on the crime scene area only resulting in approximately 40 million points. The point clouds from both sources were subsequently exported in file format las, enabling the Cloud Compare software to detect and facilitate further processing.

Figure 7(a) shows the 3D model point cloud obtained from TLS placed at various locations. It is worth noting that the 3D model point cloud highlighted an incomplete point cloud represented by circular voids in the figure where the TLS were placed despite various placements of TLS at 10 different locations and heights. This is also evident in the missing blood splatter due to obstruction of the victim's hand from a station. Figure 7(b) depicts the 3D model point cloud obtained from the micro UAV captured from various angles. It is obvious that the generated 3D model point cloud is clear, photorealistic and vibrant, except for the white void due to the lack of light.

The data from the micro UAV and TLS were also integrated using Cloud Compare software with the intent to enhance the completeness of the 3D model. Through the process of integration, a notable outcome was achieved as the resulting point cloud increase substantially, reaching a total of 72 million points. As shown in Figure 7(c), the voids present in the earlier TLS 3D model point cloud are no longer visible.

The integrated data in Cloud Compare were extracted and analyzed using the Root Mean Square Error (RMSE) to determine the accuracy in comparison with the measurements using the conventional method.

Fig. 7. Data output: 3D model point cloud of (a) TLS, (b) micro UAV, and (c) integrated point cloud.

$$\sqrt{\frac{\sum_{i=1}^{N}(yi-\hat{y}i)^2}{N}} \quad (1)$$

where yi is the true value, ŷi is the observed value, and N is the number of observations. The results of the quantitative analysis are shown in Table I.

TABLE I. MEASUREMENT ERRORS

No.	Items	Error Measurement (cm)		
		Conv-TLS	Conv-UAV	Conv-Integrated
1	Slipper	0.067	0.500	0.365
2	Glass Case 1	0.976	0.300	0.276
3	Glass Case 2	-0.008	0.170	0.162
4	Book 1	0.778	0.300	-0.127
5	Book 2	1.756	0.300	0.008
6	Wallet 1	0.263	0.300	0.234
7	Wallet 2	-0.827	-0.400	0.070
8	Bag	-0.805	0.500	-0.343
9	Water Bottle	1.490	-0.100	0.001
10	Compact Powder	-0.055	0.400	0.321
11	Cabin Length	2.153	4.000	2.560
12	Cabin Width	-3.643	2.000	0.751
13	Cabin Height	-0.698	2.000	1.554
14	Body Height	0.497	0.800	0.256
15	Body Left Arm	0.438	0.320	0.007
RMSE		0.423	0.395	0.217

Table I presents the outcome of the analysis conducted through the computation of RMSE. The label Conv denotes that the corresponding data originate from the conventional measurement approach. The measurement error is used to indicate the discrepancies between the benchmark measurements produced by the conventional method and those obtained using TLS, micro UAV and Integrated point clouds. Based on this analysis, the RMSE values for the comparison of conventional measurement against TLS, UAV, and Integrated point clouds are ±0.423 cm, ±0.395 cm, and ±0.217 cm, respectively. From a statistical standpoint, a lower RMSE value corresponds to a better performance of the given model. While there is no global standard for crime scene investigation accuracy, there are references that indicate an accuracy of 0.635 cm is accepted in the United States [18-19].

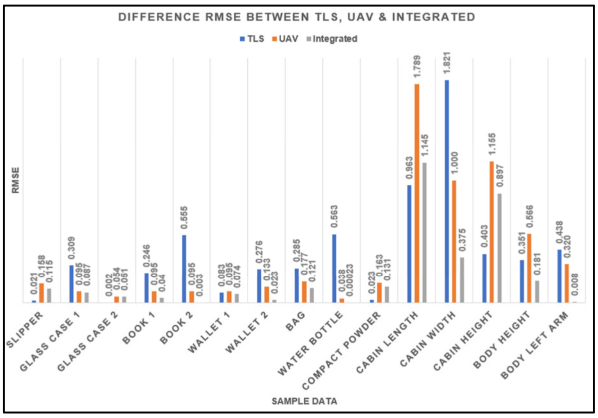


Fig. 8. RMSE of TLS, UAV, and Integrated model against the Conventional.

Figure 8 shows a visual chart comprising 13 samples of the dataset, presenting the RMSE values of TLS, UAV, and integrated data in comparison to the conventional measurements. It is observed that Cabin Length and Cabin Width exhibit slightly higher RMSE values compared to the other elements, signalling the presence of error. These differences may arise due to noise within the 3D model point cloud or due to the reflective properties of the cabin's material. It has been suggested by other researchers that the reflective surface can potentially interfere with the accuracy of optical imaging readings, including shiny, mirror-like surfaces and very dark materials [20-24]. Based on the above discussion, the quality of the resulting 3D model point cloud visualisation can be summarised in Table II. The completeness characteristics refer to the absence of void in the 3D model point cloud whilst representation and color intensity refer to the proximity to the real object. As depicted in Table II, TLS lacks completeness due to occlusion, lesser spectral information causing reduced colour intensity [25], and distorted object representation. This is aligned with the highest RMSE result for TLS as depicted in Table I. As for integrated data, the completeness and color intensity are acceptable as the occluded areas and colors are compensated for by the merging of the two datasets. The representation, however, lacks proximity to real objects due to extraneous noises from the integration of two datasets, particularly from TLS. It has been suggested that data quality for analysis could be improved with further data cleaning and noise filtering [26].

TABLE II. QUALITY OF 3D MODEL POINT CLOUD

Characteristics	TLS	Micro UAV	Integrated
Completeness	✗	✗	✓
Color Intensity	✗	✓	✓
Representation	✗	✓	✗

IV. CONCLUSION

The primary objective of this research is to assess the effectiveness and accuracy of utilizing micro UAV technology in forensic photogrammetry for evidence capture without compromising the integrity of the indoor crime scene. The generated 3D model point clouds obtained from micro the UAV and TLS were compared against conventional measurements which were used as the reference standard. Further analysis was also carried out using the integrated point cloud from both sources.

It was noted that the visualisation output of the micro UAV is superior to TLS, despite the fact that it provided a greater quantity of point cloud data covering a wider area. This study further demonstrated that the integrated data produced by TLS and micro UAV generated a 3D model point cloud that is complete and suitable for indoor forensics application. The integrated point cloud provides a higher-density point cloud thus giving realistic color to the model. However, despite having the lowest RMSE of ±0.217 cm, the integrated point cloud has its own limitations: the body of the cabin and the ladder were distorted which may be due to the reflective surface of the object and inefficient lighting. Further study is warranted to delve into resolving issues related to reflective or shiny objects and the placement of TLS for indoor environments.

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