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A Comparative Analysis of Point Clouds Acquired from UAV Photogrammetry and UAV-based LiDAR in Built Environment

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Advancements in reality capture techniques have transformed the use of 3D datasets into a crucial resource for surveying and documentation in the Architectural, Engineering, and Construction (AEC) field. Unmanned aerial vehicles (UAVs) are widely employed in this domain, offering high-quality mapping data. However, issues related to volumetric measurement accuracy in UAV-based 3D models have been observed. In contrast, UAV-based Light Detection and Ranging (LiDAR) technology has emerged as a promising alternative, with superior coverage and accuracy. This study aims to conduct a comparative analysis of point clouds acquired from a camera-equipped UAV and a LiDAR-equipped UAV. The findings reveal that UAV-based photogrammetry demonstrates less relative accuracy compared to UAV-based LiDAR, thus providing valuable insights for professionals in the AEC industry. The results of the study may help small and medium-sized construction companies that have limited resources for LiDAR investment.

Key Words: UAV, Drone, Photogrammetry, LiDAR, Point Cloud Comparison.

Introduction

Due to advancements in reality capture techniques, the utilization of 3D datasets (point clouds or meshes) has evolved into a vital resource for surveying and document administration purposes. Compared to traditional methods, new reality capture methods provide more accurate and faster documentation (Liu et al., 2023). Reality capture technology enables the translation of the physical world into a virtual environment, enabling professionals in the Architectural, Engineering, and Construction (AEC) field to effortlessly strategize, track advancements, and connect real-world models with planned designs, thereby ensuring quality control (Fobiri et al., 2022).

Drones, namely unnamed aerial vehicles (UAVs), are one of the reality capture tools that have been frequently used in AEC for the last decade. As the drone industry improves, the technology has made it possible for 3D high-quality mapping data to be easily accessible (Li & Liu, 2019). However, even though UAVs perform much better than traditional methods, volumetric measurement error might frequently occur in UAV-based 3D models, especially for high canopy closure (Guan et al., 2022; QingWang et al., 2017). On the other hand, UAV-based LiDAR, which is a relatively new technology in the construction industry, provides larger coverage and higher accuracy compared to photogrammetry. Even though both technologies can generate quality results, the accuracy, price, and applications might vary (Equator, 2023). However, while existing comparative studies have predominantly focused on agricultural and forestry research (e.g., Puliti et al., 2020; Deligiannakis et al., 2021), there is a notable absence of studies that compare these techniques within the context of the built environment. Therefore, this study aims to conduct a comparative analysis of point clouds acquired from a camera-equipped UAV and a LiDAR UAV for the built environment and construction-related studies.

Literature Review

Reality Capture in the Construction Industry

The primary objective of reality capture is to acquire geometrically accurate and visually detailed data and create digital models (Xie et al., 2022). Recently, this technology has been used in the construction industry either for completed or ongoing projects to capture information (Alizadehsalehi & Yitmen, 2023). There are several use cases of reality capture in the construction management literature. For example, Hamledari and Fischer (2021) utilized it for construction payment automation; Alizadehsalehi and Yitmen (2023) used it to develop a progress monitoring management model; and McHugh et al. (2021) developed a strategy to connect project stakeholders via reality capture. The studies have been done by using different reality capture equipment such as LiDAR scanners, photogrammetry cameras, and camera-equipped UAVs. This study aims to address the existing gap by conducting a comparative analysis of UAV-based LiDAR and photogrammetry specifically within the context of the built environment, filling a notable gap in the current research landscape predominantly focused on agricultural and forestry applications.

UAV-Based Photogrammetry

UAV-based photogrammetry utilizes collected snapshots taken by small, mounted cameras. A 3D point cloud of the designated region can be generated through either direct or indirect georeferencing techniques. Indirect georeferencing involves the procedures used to assign global coordinates to 3D measurements obtained within a localized reference frame relative to the world (Guan et al., 2022). Multiple captured images can be merged through point-of-interest identification and matching across these images. Specifically, the photogrammetric method utilizes the Structure from Motion (SfM) technique. SfM leverages overlapping images to generate a 3D point cloud of an object or a landscape (Appollonio et al., 2021). To obtain the most accurate images, it's crucial to configure the capture intervals in a way that ensures a minimum of 75% frontal overlap (with 80% being the ideal target) and 65% side overlap (with 70% being the ideal goal) (Datumate, 2023).

UAV-Based LiDAR

Cameras of drones can be combined with sensors such as LiDAR system. LIDAR, as described by Guan et al. (2022), calculates the distance to a point in the 3D environment by examining the laser beam's return, and it measures the position directly by directing laser beams to a predefined direction within the LIDAR's body frame. Compared to a camera, LiDAR is more accurate in 3D point clouds, less sensitive to light conditions, and can provide high location precision (e.g., GPS/GNSS and

Inertial Measurement Unit (IMU)) (QingWang et al., 2017). However, UAV-based LiDAR scanners are expensive, and more energy-dependent equipment compared to camera drones. Therefore, the targeted precision and other constraint should be considered when deciding to use a LiDAR drone. In a nutshell, UAV-based LiDAR and photogrammetry exhibit distinct technical variations that could be significant for specific applications. Table 1 outlines the primary advantages and disadvantages of both systems, with the information derived from the research of Lin et al. (2019), Shaw et al. (2019), and Equator Studios (2023).

Table 1
Comparison of UAV photogrammetry and UAV LiDAR

Technique	Pros	Cons
UAV-based photogrammetry	High-resolution, precise 3D topographic data	Highly depends on sunlight.
	Low-cost equipment	Survey Ground Control Points necessary for georeferencing
	Ease of deployment	Relatively poor accuracy
UAV-based LiDAR	LiDAR data can be collected day or night	High-cost equipment
	Higher relative and absolute accuracy	Survey interval limited by cost and weather condition
	Larger spatial coverage	
	Direct topographic reconstruction	

Methodology

While UAV-based scanning is becoming increasingly popular in the built environment, companies are hesitant to invest significant amount in technologies whose benefits and costs they are uncertain about. Therefore, there is a need to find out whether UAV-based photogrammetry, a more cost-effective alternative to UAV-based LiDAR, offers an affordable solution for construction companies seeking to integrate reality capture. Accordingly, the following sections explain the research approach in comparing both methods.

Case Study and RC Instruments

A case study was conducted to compare two drone-capturing approaches. The Robins & Morton Construction Field Lab on Auburn University campus, with a site area of approximately three acres, was selected for the data collection. The site is illustrated in Figure 1.

Figure 1. Captured area - educational facility.

Data Collection and Analysis

Figure 2 shows the drones used in the data collection. The first capture was done on August 23, 2023, with EasyOneLiDARUHR. EasyOneLiDARUHR drone includes a LiDAR Sensor (Hesai Pandar XT-32), a Camera Sensor (1x Microdrones CMOS APS-C 26 MP), and Georeferencing (Trimble APX-15 UAV). The second capture was conducted by using DJI Mavic 3E on September 28, 2023. Multiple captures were taken from several heights and angles. Also, Table 2 shows the capturing detail for both equipment. For EasyOneLiDARUHR, LP360 software was used to produce the point cloud, while Metashape software was used for DJI Mavic 3E capture.

a) UAV-based LiDAR drone (EasyOneLiDARUHR)

b) UAV-based photogrammetry drone (DJI Mavic 3E)

Figure 2. Equipments used for data collection.

Table 2
Data Collection Information

Equipment	**DJI Mavic 3E**	**EasyOneLiDARUHR**
Height	120 ft (36.57 m), 150 ft (45.72 m), 200 ft (60.96 m)	260 ft (79.25 m)
Camera Angle	45°,60°, and 90°	90°
Captured Data	4,324 photos	A point cloud of 44.6 M points
Total Duration	01:20:06 (hh:mm:ss)	00:14:35

Comparing Point Clouds

Point clouds represent a valuable source of three-dimensional shape information obtained through reality capture devices, and the process of comparing point clouds serves the crucial purpose of quantifying the spatial disparity between a specific dataset of point cloud information and a distinct reference model or dataset. This study uses CloudCompare software to compare the performance of two different drone captures. CloudCompare is an open-source 3D visualization and computational software that is widely used in different fields (Dewez et al., 2016). The applied methodology's sequential flow, detailing the step-by-step processes and procedures is illustrated in Figure 3.

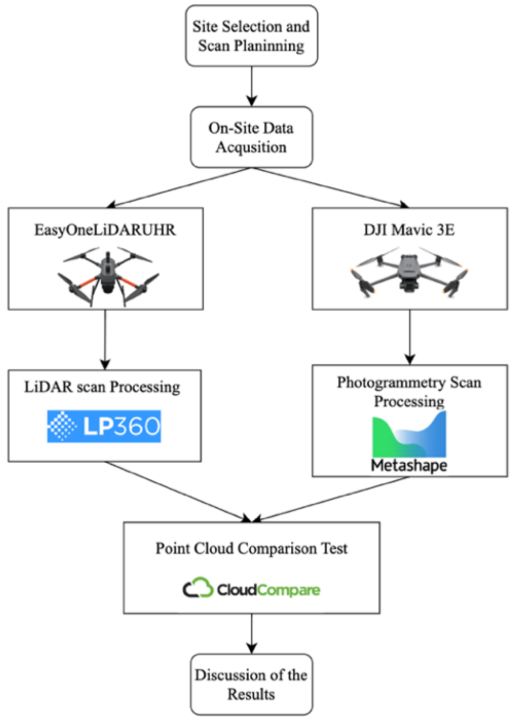
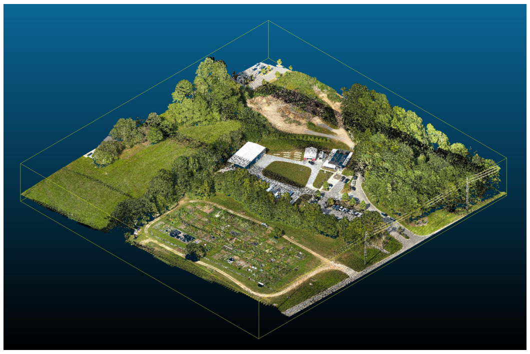


Figure 3. Data collection and analysis framework.

In the process of comparing the point clouds obtained from a photogrammetry drone and a LiDAR drone, as illustrated in Figure 4, a series of preparatory steps were undertaken using the CloudCompare software. These steps involved aligning all the captured data, and this alignment was achieved through the utilization of six strategically placed reference points. The data captured by the photogrammetry drone at three distinct heights – 120 feet, 150 feet, and 200 feet – were merged to create a composite model. This composite model then served as the basis for comparing the LiDAR capture. To ensure efficient processing and analysis, both datasets were subsampled to contain approximately 10 million points each.

It is important to clarify that the central objective of this comparative study was to evaluate the precision and accuracy of the two UAV-based data acquisition tools rather than focusing on their area coverage. As anticipated, the photogrammetry drone exhibited limitations in capturing the intricate details of the surrounding trees when compared to the LiDAR drone. Consequently, a selective approach was adopted, wherein only those points with a discrepancy falling within the range of 0 to 20 centimeters were extracted and considered for further analysis. This meticulous culling process effectively eliminated areas that were not adequately captured by the photogrammetry drone, facilitating a more focused assessment of the comparative performance of these two data acquisition technologies.



a) UAV-based LiDAR point cloud.

b) UAV-based photogrammetry point cloud.

Figure 4. Point clouds from LiDAR and photogrammetry drones.

Results and Discussion

To compare the accuracy of UAV-based photogrammetry point clouds and UAV-based LiDAR point clouds, a quantitive comparison was held on CloudCompare software. The octree level was set to 8 to get a high level of detail in an acceptable time. Figure 5 shows the result of the comparison. In the comparison, the LiDAR point cloud is considered a benchmark due to LiDAR is more accurate compared to photogrammetry (Khanal et al, 2020; Rogers et al., 2020). Due to the difference in coverage areas of the compared point clouds, the results gave a highly unmatched model. Also, the main purpose of this study is to compare UAV-based LiDAR and photogrammetry for the built environment. Therefore, the comparison was repeated for the field lab area excluding the trees covered by both point clouds. The area is illustrated in Figure 6.

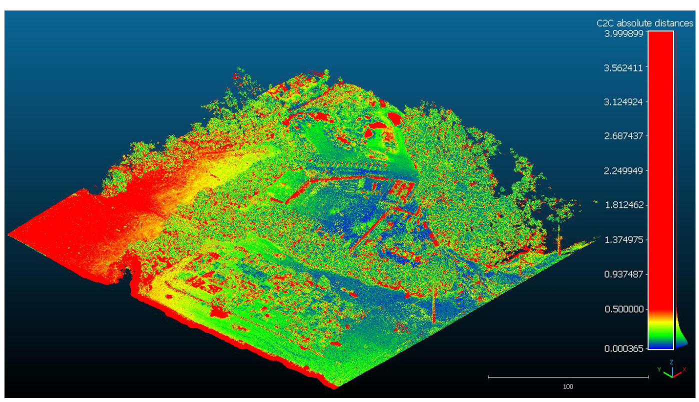


Figure 5. Comparison test result. (Reference: UAV-based LiDAR point cloud; Compared: UAV-based photogrammetry).

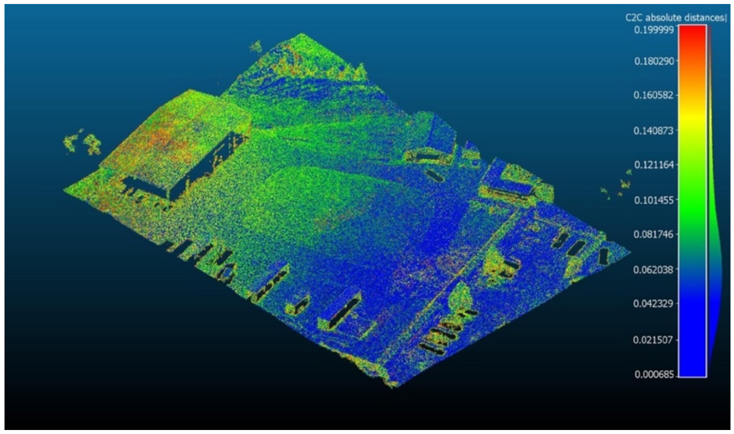


Figure 6. Comparison test result for the selected area. (Reference: UAV-based LiDAR point cloud; Compared: UAV-based photogrammetry).

The comparison result for the selected area showed that the mean difference is 0.078m (0.256 ft) with a standard deviation of 0.042m (0.137 ft) (Figure 7). The mean value represents the average distance of UAV-based photogrammetry from the LiDAR cloud point, while the A standard deviation of 0.042 meters suggests that the majority of points in the clouds are within 0.042 meters of the mean value. The results showed that more than half of the points have a distance of less than 0.0062m. These findings indicate that the UAV-based photogrammetry is relatively less accurate in comparison to the UAV-based LiDAR (Liu et al., 2023).

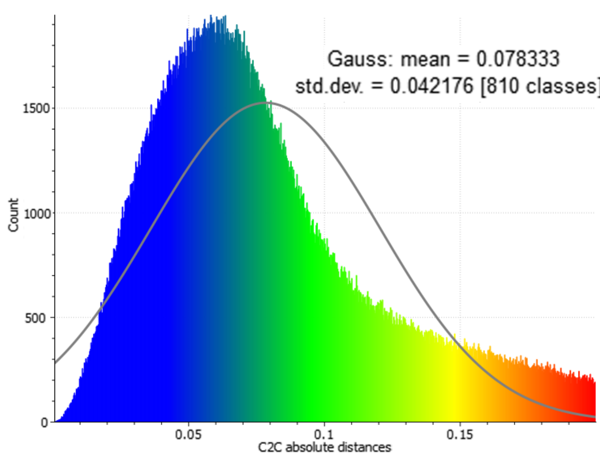


Figure 7. Mean distance and standard deviation of the corresponding points in the two point clouds.

A visual comparison reveals that the most significant errors are concentrated around the roof of the workshop facility within the scanned area. Researchers believe that this difference is likely a result of the reflection of the photogrammetry point cloud, possibly influenced by the color of the roof. Additionally, it's important to acknowledge that the scans were collected one month apart from each other. This time gap can potentially introduce differences in the data due to various environmental and seasonal factors. Changes in lighting conditions and weather could contribute to discrepancies in the point clouds. Furthermore, since the LiDAR data was collected at a fixed 90° angle, the geometry of the roof may have contributed to variations in the point clouds.

Conclusion

This comparative analysis of UAV-based photogrammetry and UAV-based LiDAR point clouds reveals significant insights regarding their accuracy for built environment-related studies. The initial comparison, which considered LiDAR point clouds as the benchmark, displayed a notable disparity due to differing coverage areas of the equipment. To mitigate this, the researchers conducted a comparison within a selected area, excluding trees covered by both technologies. In this context, the mean difference was found to be 0.078m (0.256 ft), with a standard deviation of 0.042m (0.137 ft). These results indicate that UAV-based photogrammetry can offer a relatively less accurate alternative to UAV-based LiDAR. The choice between these technologies should consider factors such as accuracy, cost, and specific use cases, offering valuable guidance for professionals seeking the most suitable reality capture solution in the AEC field.

In terms of practical contributions, small and medium-sized construction companies may utilize UAV-based photogrammetry for several purposes. UAV-based photogrammetry allows for broader accessibility, making it a viable choice for construction projects where budget constraints might otherwise limit the use of LiDAR technology. The study also has several limitations. The study did not comprehensively explore the impact of environmental factors, such as weather conditions, which could be a critical consideration in real-world construction scenarios. Moreover, the applicability of these results may vary depending on the specific context and requirements of individual construction projects, underscoring the need for customized assessments. Therefore, future studies may include more case studies for the construction industry.

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