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Comparison of UAV-LIDAR and Aerial Photogrammetry in Rural Areas with High Vegetation

Arli Llabani[1], Freskida Abazaj[2]
[1]Faculty of Civil Engineering, Polytechnic University of Tirana, Tirana, Albania
[2]Faculty of Civil Engineering, Polytechnic University of Tirana, Tirana, Albania

***Abstract*—*This study presents a comparative analysis of UAV-based Light Detection and Ranging (LiDAR) and aerial photogrammetry for mapping and surveying in rural areas. Both technologies have revolutionized geospatial data acquisition, offering unique advantages and facing specific challenges. UAV-LiDAR uses laser pulses to create high-resolution three-dimensional models, excelling in areas with dense vegetation and complex terrain by providing precise elevation data and the ability to penetrate canopy cover. Aerial photogrammetry, on the other hand, employs high-resolution images to generate 3D models through photogrammetric techniques, performing well in open fields and less vegetated areas due to its high-resolution orthomosaics and cost-effectiveness. Field studies conducted in various rural settings—agricultural lands, forests, and mixed-use landscapes—served as the basis for comparison, focusing on metrics such as data accuracy, point density, processing time, and cost. UAV-LiDAR demonstrated superior performance in densely vegetated and topographically complex areas, whereas aerial photogrammetry was more efficient and economical in open and semi-open landscapes. The study also explores the potential of integrating both technologies to leverage their strengths, enhancing overall data quality and providing comprehensive geospatial insights. The findings offer practical guidelines for selecting the appropriate technology based on specific project requirements, highlighting UAV-LiDAR's suitability for detailed topographic surveys and vegetation analysis, and aerial photogrammetry's advantages for broader area coverage and budget-sensitive projects. This comparison underscores the transformative impact of UAV technologies in rural mapping and supports informed decision-making in environmental monitoring, agriculture, and infrastructure development.*

Keywords*— *LIDAR, UAV, accuracy, point cloud, orthomosaic.

I. INTRODUCTION

The rapid advancements in Unmanned Aerial Vehicle (UAV) technologies have ushered in a new era of geospatial data acquisition, particularly enhancing the precision and efficiency of surveying and mapping tasks in various environments. In rural areas, where traditional ground-based surveying methods often face significant logistical challenges due to difficult terrain and vast expanses, UAVs equipped with advanced sensors such as Light Detection and Ranging (LiDAR) and high-resolution cameras for photogrammetry have proven to be game changers.

UAV-LiDAR and aerial photogrammetry represent two of the most prominent technologies in this domain. Each brings distinct methodologies and advantages to the table, making them suitable for different types of rural surveying projects. UAV-LiDAR uses laser pulses emitted from a sensor to measure distances to the earth's surface, generating high-resolution three-dimensional models of the terrain, vegetation, and infrastructure. This technology is particularly effective in densely vegetated areas, as it can penetrate through canopy layers to capture detailed ground information that is otherwise obscured.

On the other hand, aerial photogrammetry involves capturing high-resolution images from UAV-mounted cameras. These images are processed using photogrammetric techniques to create 3D models and orthomosaics. This method relies heavily on overlapping imagery and advanced algorithms to reconstruct terrain features accurately. Aerial photogrammetry is known for its ability to produce detailed and visually rich maps, making it ideal for applications that require high-resolution imagery over large areas with minimal vegetative cover.

The comparison between these two technologies is crucial for determining the most suitable method for specific rural mapping tasks. In rural environments, the diversity of landscapes—ranging from agricultural fields and pastures to forests and mountainous regions—poses unique challenges for accurate data collection and analysis. The choice between UAV-LiDAR and aerial photogrammetry often hinges on factors such as the type of terrain, the presence of vegetation, the required data accuracy, and the project's budget constraints.

This study aims to provide a comprehensive comparison of UAV-LiDAR and aerial photogrammetry in rural areas, focusing on their respective strengths, limitations, and practical applications. By conducting field studies in diverse rural settings, we analyze metrics such as data accuracy, point density, processing time, and overall workflow efficiency. This analysis not only highlights the scenarios where one technology may outperform the other but also explores the potential for integrating both methods to maximize data quality and utility.

UAV-LiDAR's ability to produce high-density point clouds and accurate Digital Elevation Models (DEMs) is particularly beneficial in forested and rugged terrains where traditional photogrammetry might struggle. In contrast, aerial photogrammetry excels in providing high-resolution orthomosaics that are invaluable for agricultural monitoring, landscape planning, and infrastructure development. Additionally, the economic aspects of both technologies are considered, as cost-effectiveness plays a critical role in the feasibility of large-scale rural mapping projects.

Furthermore, the integration of UAV-LiDAR and aerial photogrammetry offers a hybrid approach that leverages the advantages of both technologies. This combined method can provide comprehensive geospatial insights, making it a powerful tool for rural area management. By examining the practical outcomes of using UAV-LiDAR, aerial photogrammetry, and their integration, this study aims to offer clear guidelines for selecting the appropriate technology based on specific project needs.

In conclusion, the comparative study of UAV-LiDAR and aerial photogrammetry in rural areas underscores the transformative potential of UAV-based geospatial data acquisition. It supports more informed decision-making in environmental monitoring, agricultural planning, and infrastructure development, ultimately contributing to the sustainable management of rural landscapes. This introduction sets the stage for an in-depth exploration of how these advanced technologies can be optimized to address the unique challenges of rural surveying and mapping.

II. METHODOLOGY

A. *Case study*

The village of Dhermi located in the south of Albania was selected as a case study in this paper. The settlement of Dhërmi is located in Albania's Vlorë County. It is a component of the Himarë municipality. The village is situated at the same distance north of Sarandë, the southern metropolis, and 42 kilometers south of Vlorë. Constructed at an estimated altitude of 200 meters on a Ceraunian Mountain slope, it consists of three neighborhoods: Gjilek, Kondraq, Kallami, and Dhërmi. The mountains drop away to the southwest toward the Ionian coast, with Corfu seen far to the south. The settlement of Palasë is located nearby. The national road separates the village from the beach. The village is located on the slope of the mountain, in rugged terrain and being in the oldest villages of the construction area, the characteristic, where the tower style stands out.

Fig. 1. Location of the Fortress of Bashtova (Google Earth).

B. *UAV LIDAR*

UAV Lidar (Light Detection and Ranging) is a transformative technology in remote sensing, enabling high-resolution and accurate 3D mapping from unmanned aerial vehicles. This technology uses laser pulses to measure distances to the Earth's surface, creating detailed point clouds that represent the terrain and objects with remarkable precision. Mounted on UAVs, Lidar systems offer a versatile solution for capturing topographic data in various environments, from dense forests to urban landscapes. The integration of GPS and Inertial Measurement Units (IMUs) ensures that the spatial data is georeferenced accurately, allowing for precise mapping and analysis. UAV Lidar is particularly valuable in applications such as environmental monitoring, forestry management, infrastructure inspection, and disaster response. Its ability to penetrate vegetation and generate accurate ground models makes it superior to traditional photogrammetry in certain contexts. Furthermore, UAV Lidar surveys are highly efficient, reducing the time and labor required compared to ground-based surveys. The rapid data acquisition, coupled with advanced processing software, enables the generation of Digital Elevation Models (DEMs), Digital Surface Models (DSMs), and other analytical products that inform decision-making and resource management. As UAV technology continues to advance, the capabilities of Lidar systems are expanding, offering even greater precision, longer range, and enhanced integration with other remote sensing technologies.

In this paper, DJI Matrice 300 RTK with a Zenmuse L1 camera was used to perform the UAV-Lidar mission. The propulsion technology of the DJI Matrice 300 RTK is based on quadcopters. This indicates that it is propelled and lifted by four rotors. High-performance brushless motors, engineered to deliver optimal power and efficiency, drive the rotors. Additionally, the motors are made to be dependable and quiet, which is crucial for professional use. A powerful GPS system that delivers precise navigation and positioning powers the drone. Additionally, it includes an integrated obstacle avoidance system that finds and avoids impediments in its route using sophisticated sensors and algorithms.

A powerful and incredibly light Livox Lidar module with a 70° field of view, a high-accuracy IMU, and a 20-megapixel camera with a 1-inch CMOS sensor—all suitable for use in photogrammetry missions—are all integrated within the Zenmuse L1. A large area (up to 2km2) of point cloud data may be collected in a single trip by the Zenmuse L1, which can also produce true-color point cloud models in real time. The ease and speed at which high-quality Lidar data may be captured is unparalleled, with a Point Rate of 240,000 points per second and a detection range of 450 meters.

The L1 can accommodate three returns, which allows the point rate to be boosted to 480,000 points per second. The module is compatible with Livox's own Non-repetitive Scanning Mode as well as Line Scan Mode. This enables the sensor to collect data in any direction rather than along a predetermined plane, and will result in complete coverage of the region of interest in a very short length of time. Vegetation canopies and foliage are easily penetrated by the Zenmuse L1

Lidar solution. The L1's IP54 classification allows it to be utilized in challenging weather situations, increasing the number of data collection chances. The DJI L1 can continuously use the visual assistant camera to gather orientation data and maintain system accuracy in a short amount of time if the aircraft unexpectedly loses GNSS communication.

When choosing a specialized program at this stage of flight planning for LIDAR scanning, there are a few general criteria that are particularly important to consider. These include keeping the same flight height even as the terrain below changes, especially in large dislevels. Accurately calculating the longitudinal and transverse requires proper support of the scanner's parameters in relation to the camera and scanning field.

To plan the operation and establish the flight parameters, we utilized 3D survey app. These factors are simply adjustable, and the process of automatically generating routes is accomplished by contouring our area of interest and specifying the flight parameters.

The GPS base must be turned on and continually take static measurements about five minutes prior to the flight and one minute after the drone takes off, in addition to the LIDAR device, which takes a few minutes to self-calibrate. With an accuracy of 2-3 cm, the National Albanian Active GNSS Network (ALBCORS) system is used to measure the coordinates of the temporary base using the RTK method. These data were used to post-process the data using the PPK technique, which allowed for the precise creation of routes and IMU data.

We choose 100 m height and 6 m/s speed of DJI Matrice 300 RTK to perform this flight path as shown in Figure 2. A front overlap of 75% and a side overlap of 80% were set.

Fig. 2. UAV LIDAR flight mission planning with DJI Matrice 300 RTK L1.

C. Aerial Photogrammetry

Aerial photogrammetry is a highly effective remote sensing technique that involves capturing overlapping photographs from an aircraft, typically an airplane or UAV, to create precise and detailed 3D models and maps of the Earth's surface. This method relies on the principles of triangulation, where the same point on the ground is photographed from multiple angles. By analyzing the differences in these images, specialized software can calculate the exact position and elevation of each point, resulting in highly accurate topographic maps, orthophotos, and digital terrain models. Aerial photogrammetry is widely used in various fields, including urban planning, agriculture, archaeology, and environmental monitoring. Its ability to cover large areas quickly and generate high-resolution imagery makes it an indispensable tool for projects requiring detailed spatial data.

The advent of UAV technology has significantly enhanced the accessibility and flexibility of photogrammetric surveys, allowing for frequent and cost-effective data collection over difficult-to-reach or hazardous areas. Furthermore, advancements in camera technology and image processing algorithms have improved the accuracy and resolution of photogrammetric outputs. The integration of GPS and IMU data with aerial images ensures precise georeferencing, making the resultant 3D models and maps reliable for a range of applications. Despite challenges such as varying light conditions and the need for clear skies, aerial photogrammetry remains a cornerstone of modern geospatial data acquisition, providing critical insights for effective decision-making and resource management.

In this probe, an aerial evaluation of Dhermi village was conducted using a DJI Matrice 300 RTK equipped with a Zenmuse P1 camera. A quadcopter propulsion system with four rotors for lifting and propulsion powers the DJI Matrice 300 RTK. These brushless, high-performance motors are made to deliver optimal power and efficiency while maintaining dependability and silence. The DJI Matrice 300 RTK also features an inbuilt obstacle avoidance system that uses sophisticated sensors and algorithms to identify and steer clear of obstacles while also having a powerful GPS for precise positioning and steering.

With the Zenmuse P1, which boasts the largest image sensor with the greatest resolution ever, we utilized the DJI Matrice 300 RTK. Prime lens changing is also supported by the Zenmuse P1 camera. With these lenses, 45-megapixel aerial images may be captured, and the camera is fixed on a three-axis gimbal. For this investigation, the DJI Zenmuse P1 with a 35mm focus lens was put to the test.

In order to acquire oblique images, various subpaths facing the center of the site were used in addition to the main flight path for UAV photogrammetry, which was carried out using 3D survey software. When compared to a typical 2D Area Route mission at the same site, this strategy uses greater battery power and flying time. In Figure 3, we use a DJI Matrice 300 RTK with a P1 camera at a height of 100 meters and a speed of 6.2 meters per second to execute this flight route. It was decided to set an 80% front overlap and an 85% side overlap.

Fig. 3. Aerial Photogrammetry flight mission planning with DJI Matrice 300 RTK P1.

III. RESULTS

A. UAV LIDAR data processing

UAV Lidar data processing is a multi-stage workflow that converts raw laser scans captured by UAV-mounted Lidar systems into actionable geospatial insights. The process begins with the transfer and backup of raw Lidar data from the UAV to a secure storage system to ensure data integrity and prevent loss. The initial dataset comprises millions of individual data points, each representing a laser pulse return. Specialized software is employed to convert these raw points into a coherent point cloud, a detailed 3D representation of the surveyed area. This point cloud often includes noise and outliers caused by atmospheric interference or sensor errors, necessitating the application of filtering techniques to clean the data.

Once filtered, the point cloud undergoes georeferencing, where it is accurately aligned with GPS and Inertial Measurement Unit (IMU) data to ensure precise spatial positioning. This step is critical for integrating the Lidar data with other geospatial datasets and for subsequent analysis. The georeferenced point cloud is then classified into different categories, such as ground, vegetation, and built structures, using automated algorithms complemented by manual verification to enhance accuracy. This classification allows for the extraction of specific features and the generation of detailed Digital Elevation Models (DEMs) and Digital Surface Models (DSMs). Further processing might include the creation of contour maps, analysis of vegetation heights, and the identification of temporal changes by comparing current data with historical datasets.

Quality assurance is integral throughout the process, involving cross-referencing with ground truth data and other validation techniques to ensure the data's accuracy and reliability. Finally, advanced visualization tools and Geographic Information System (GIS) platforms are utilized to present the processed data in a comprehensible and interactive format, making it accessible for various applications such as urban planning, environmental monitoring, disaster management, and infrastructure development. Through meticulous processing, UAV Lidar data transforms from raw sensor output to a powerful resource that supports informed decision-making and strategic planning across numerous fields.

Preprocessing normally involves the employment of specific applications linked to particular brand-name scanning machines. LIDAR scanner hardware manufacturers produce these and the corresponding instructions. In this instance, lidar data processing was done using DJI Terra. The fundamental technology of DJI Terra is photogrammetry, which is used to reconstruct 3D models. It facilitates a variety of precise and effective visible light reconstruction in two and three dimensions, as well as data processing using DJI LiDAR. With DJI Terra, we are able to analyze point cloud data from the Zenmuse LiDAR with high accuracy. This includes calculating routes, precisely fusing point cloud and visible light data, optimizing point cloud accuracy, extracting ground points, creating DEMs, and producing mission reports.

At this point, the processing flow looks like this: The base file (observation data), the IMU data (POS data), the Lidar files, and the photos are among the files we have prepared. After that, we finished configuring the specifications of our LIDAR equipment and selected UTM Zone 34N (epsg:32634) as the necessary coordinate system. Additionally, we picked the generation method based on the routes, manually selected the routes eliminated the trajectories that alternated between the routes, and decided whether or not to add color to the 3D rain using RGB camera photos. For our entire area, the processing time for all trajectories and the creation of a 3-dimensional point cloud was 55 minutes for uncolored points and 75 minutes for colored points. Following the pre-arrival process's acquisition of a point cloud, the next stage involved quality control, plan and height accuracy monitoring, and a variety of analyses of this material based on the demands at hand. Since the input in this process is a number of points in the form of a cloud, georeferenced and with data such as intensity, RGB color, number of returns, etc. in a format that is easily processed by any GIS program that supports 3D networks, the computer programs for this phase are diverse and independent of the physical equipment used. In this instance, we processed some data and verified accuracy and quality using the Global Mapper application.

With about 840,378 points, 1689 images, 2.43 pixels in size, 5472 x 3648 resolution, and a camera centering error of 3.8 cm, the model displayed in Figure 4 has a high level of accuracy. We were able to obtain the DSM with a 3.6 cm resolution.

Fig. 4. Point Cloud generated from UAV LIDAR.

B. Aerial Photogrammetry data processing

Aerial photogrammetry data processing is a sophisticated procedure that transforms overlapping aerial photographs captured from aircraft or UAVs into precise and detailed 3D models and maps of the Earth's surface. The process begins with the collection of high-resolution imagery covering the target area, ensuring sufficient overlap between consecutive images. These images are then processed using specialized photogrammetric software, which employs principles of triangulation to calculate the precise position and elevation of each point on the ground. Through a series of automated algorithms, common features across multiple images are identified and matched, allowing for the generation of a dense point cloud representing the terrain. This point cloud is further refined through filtering techniques to remove noise and outliers, resulting in a more accurate representation of the landscape.

Georeferencing is a crucial step in the process, where the photogrammetric outputs are aligned with GPS and IMU data to ensure accurate spatial positioning. Once georeferenced, the data can be classified into different categories such as ground, vegetation, and structures, enabling the extraction of specific features and the creation of detailed Digital Elevation Models (DEMs) and Digital Surface Models (DSMs). Further analysis may involve generating contour maps, assessing vegetation health, or identifying changes over time by comparing current data with historical imagery.

Quality assurance measures, including validation against ground truth data, are implemented throughout the process to verify the accuracy and reliability of the photogrammetric outputs. Advanced visualization tools and Geographic Information System (GIS) platforms are then utilized to present the processed data in a user-friendly format, facilitating its interpretation and utilization for various applications such as urban planning, agriculture, environmental monitoring, and infrastructure development. Aerial photogrammetry data processing thus plays a pivotal role in transforming raw aerial imagery into valuable geospatial information that supports informed decision-making and planning across diverse industries and sectors.

The UAV pictures were processed using the Pix4DMapper software. This software produces high-precision deliverables like orthophotos and Digital Surface Models (DSM) by automatically transforming the drone's photos. Pix4DMapper reconstructs the scene from many overlapping pictures using the SfM (Structure from Motion) approach.

First, preliminary processing was done in Pix4DMapper for processing aerial pictures. PIX4Dmapper calculates the important points of the images before starting the first processing. These salient features are used by this software to identify photo-to-photo similarities. The software then performed Bundle Block Adjustment (BBA) and Automatic Aerial Triangulation (AAT) once this first match was discovered.

The coordinate system for the study's final products, UTM Zone 34N (epsg: 32634), was selected. The relevant template was then defined as 3D maps in the Pix4DMapper software, giving us the aforementioned items. This method produced an orthophoto and a digital elevation model (DEM) of the surveyed area.

After the first stage of image processing in Pix4DMapper, the Point Cloud and 3D mesh building process came next.

Typically, point clouds are created by measuring a large number of points on the exterior surfaces of nearby objects using 3D scanners or photogrammetry software. A multitude of applications, including mass customization, animation, visualization, metrology, and 3D computer-aided design (CAD) models for manufactured parts, use point clouds, which are created using 3D scanning techniques.

With about 820,289 points, 1620 images, 2.41 pixels in size, 5472 x 3648 resolution, and a camera centering error of 4.2 cm, the model displayed in Figure 5 has a high level of accuracy. We were able to obtain the DSM with a 4 cm resolution.


Fig. 5. Point Cloud generated from Aerial Photogrammetry using Pix4Dmapper.

C. Comparison between UAV LIDAR and Aerial Photogrammetry data.

The comparison between UAV Lidar and aerial photogrammetry represents a critical evaluation of two prominent remote sensing techniques, each offering unique advantages and applications in geospatial data acquisition. UAV Lidar, utilizing laser pulses emitted from onboard sensors, excels in capturing highly accurate and dense point clouds of the Earth's surface, regardless of terrain or vegetation cover. This technology provides unparalleled precision in elevation measurements, making it ideal for applications requiring detailed topographic mappings, such as urban planning, forestry management, and infrastructure inspection. Its ability to penetrate dense vegetation and capture ground elevation beneath canopy cover sets it apart, particularly in areas where traditional aerial photogrammetry may struggle. Conversely, aerial photogrammetry harnesses overlapping aerial imagery to generate 3D models and maps through triangulation techniques. While lacking the precision of Lidar in elevation measurements, photogrammetry offers advantages in terms of cost-effectiveness, scalability, and flexibility. With advancements in camera technology and image processing algorithms, aerial photogrammetry can achieve high-resolution outputs suitable for a wide range of applications, including land-use planning, environmental monitoring, and archaeological site mapping. The choice between UAV Lidar and aerial photogrammetry ultimately depends on the specific requirements of the project, considering factors such as resolution, accuracy, terrain complexity, and budget constraints. In many cases, a combination of both technologies may offer the most comprehensive solution, leveraging the strengths of each to achieve optimal results. As technology continues to evolve, the synergy between UAV Lidar and aerial photogrammetry promises to further enhance the capabilities of remote sensing for diverse applications, driving innovation and efficiency in geospatial data acquisition and analysis.

The results of our comparison of accuracy in the selected field utilizing two distinct approaches are shown in this section. According to the data, UAV Lidar performs better in surveys of rural areas with dense vegetation than UAV photogrammetry.

Cloud Compare software was used to compare the point clouds created by different methods. We were able to ascertain the clouds' distance from one another after entering them into CloudCompare. The UAV Lidar method measurements produced the point cloud that was chosen as a reference.

Figure 6 shows how to identify errors and noise in the point cloud obtained from UAV photogrammetry. The lidar-acquired point cloud offers superior geometric accuracy.

The standard deviation was 7.427 mm, and the mean RMS was 4.25 mm.

Lidar and UAV photogrammetry can complement one another by leveraging one technology's advantages over the other. UAV Lidar is a more expensive technology than photogrammetric surveys, and obtaining laser scans requires more skill than simply collecting pictures for 3D photo reconstructions. On the other hand, UAV photogrammetry is faster, more flexible, efficient, and able to collect accurate, high-quality data for complex objects.

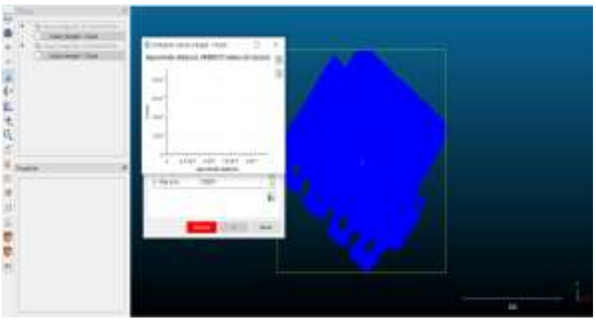

Fig. 6. Comparison of Point Clouds in CloudCompare Software.

IV. CONCLUSIONS

This study compared the use of aerial photogrammetry and UAV Lidar in Dhermi village to do a 3D survey. In order to address the important issue raised, we performed an accuracy analysis of each remote sensing point cloud using CloudCompare. We so tried to compare the point clouds that TLS and UAV created. Following analysis of our data, we discovered that the point clouds from the LIDAR and UAV varied by 0.42 centimeters. The results of the investigation show that for surveying rural areas, LIDAr provides a constant accuracy that is superior to UAV Photogrammetry. We were able to determine a mean RMS of 4.25 mm and a standard deviation of 7.427 mm by comparing the point clouds generated by TLS and UAV using the CloudCompare program. The precision acquired from the UAV Lidar technique for constructing the point cloud was 3.6 cm, whereas the accuracy obtained by aerial photogrammetry was 4 cm. In addition to 3D modeling, this work provides a helpful and straightforward research plan for comparison analysis, LIDAR measurements, and UAV photogrammetry. The study and conclusions presented in this article make it clear that the strategy covered in the article is suitable for survey-related inquiries. Both technologies are generally recommended for use in rural area surveys. It is important to keep in mind that the UAV method may require additional specialized equipment and expertise, and that it may be affected by factors such as anomalies in the air or subpar image processing. Because it requires less time to capture the area that must be measured, UAV LIDAR is more cost-effective than UAV Photogrammetry.

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