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COMPARISON ASSESSMENT OF DIGITAL 3D MODELS OBTAINED BY DRONE-BASED LIDAR AND DRONE IMAGERY

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ABSTRACT:

The purpose of this study is to assess the potential of drone airborne LiDAR technology in Morocco in comparison with drone photogrammetry. The cost and complexity of the equipment which includes a laser scanner, an inertial measurement unit, a positioning system and a platform are among the causes limiting its use. Furthermore, this study was motivated by the following reasons: (1) Limited number of studies in Morocco on drone-based LiDAR technology applications, (2) Lack of study on the parameters that influence the quality of drone-based LiDAR surveys as well as on the evaluation of the accuracy of derived products. In this study, the evaluation of LiDAR technology was carried out by an analysis of the geometric accuracy of the 3D products generated: Digital Terrain Model (DTM), Digital Surface Model (DSM) and Digital Canopy Model (DCM). We conduct a comparison with the products generated by drone photogrammetry and GNSS surveys. Several tests were carried out to analyse the parameters that influence the mission results namely height, overlap, drone speed and laser pulse frequency. After data collection, the processing phase was carried out. It includes: the cleaning, the consolidation then the classification of point clouds and the generation of the various digital models. This project also made it possible to propose and validate a workflow for the processing, the classification of point clouds and the generation of 3D digital products derived from the processing of LiDAR data acquired by drone.

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) are widely used for mapping and 3D modelling in various applications. RGB and spectral Cameras and LiDAR (Light Detection and Ranging) are the most commonly used sensors. Mapping with imagery-based approaches is considered to be an economical and effective option and is often conducted using Structure from Motion techniques to generate point clouds and orthophotos. LiDAR sensors onboard UAVs are also used to derive directly point clouds of the area of study and obtain 3D models of the scene.
LiDAR is a surveying technique that uses light in the form of a pulsed laser to measure distances and determine a 3D position. LiDAR has terrestrial, airborne and mobile applications and is used to create precise, high-resolution point clouds of objects. The drone-based airborne LiDAR is an important tool for collecting precise and dense 3D point clouds safely, quickly and cost effectively. Many applications use this technology and new ones are regularly developed in the fields of geology, land administration, urban monitoring, agriculture, forestry, and infrastructure inspection.
Airborne LiDAR systems by drones have many advantages. It is an active technology directly providing information on the distance between the sensors and the targets reached. This information is then georeferenced and used to ultimately provide a three-dimensional point cloud. Additionally, depending on the geometry of the objects illuminated by the laser beam, multiple back scatterings may be recorded for a single laser pulse using multi-echo LiDAR systems. This capacity allowed rapid adoption for the study of forest environments, then for more specific cases such as auscultation of infrastructures, monitoring of high-voltage lines or a global mapping of the urban environment. LiDAR data is also very popular in all applications requiring a high-quality 3D surface representation, such as the 3D reconstruction of cities.

Unmanned aerial vehicles (UAVs) are becoming more popular for many applications because of their capability to carry advanced sensors and collect both high temporal and high spatial resolution data at a relatively low cost. They can provide accurate spatial information and are used in various applications including mining industry (Shahmoradi et al., 2020), urban traffic monitoring (Barmpounakis et al., 2016), precision agriculture (Tsouros et al., 2019) infrastructure monitoring (Greenwood et al., 2019), construction management (Li et al., 2019), and archaeological documentation (Lin et al., 2019).

Products derived from LiDAR and imagery have been evaluated and compared in different studies. (Zhou et al., 2020) conducted a study where derived LiDAR and image-based point clouds are investigated and compared in terms of their absolute and relative accuracy. Datasets were collected over a study site with different geomorphic features: grass, pavement, and building roof. Thiel and Schmullius (2017) compared UAV image-based point clouds and manned airborne LiDAR data over a forested

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area. UAV-based photogrammetry and LiDAR were compared in a study conducted by Shaw et al. (2019) for beach monitoring. Lin et al. (2019) evaluated the relative performance of UAV LiDAR in mapping coastal environment when compared to the UAV photogrammetry. Guillaume et al. (2021) in a study for Alpine ecology implemented a multiscale framework and compare 3D models variables produced by UAV-LiDAR and stereo-photogrammetry methods, with the aim of assessing their relevance and utility in species distribution modelling.
In the following of this article, we will present a study carried out in Morocco for the evaluation of the 3D products derived from a mission by LIDAR in comparison with those of a mission by drone imagery.
The next section will be devoted to the description of the material and the methodology of the study, followed by the presentation of the results and a discussion of the evaluation carried out in this study. The article will end with a conclusion.

2. MATERIAL AND METHOD

2.1 Study area

The area chosen for this study is a private property with an area of 20 Ha located southwest of the city of Marrakech, Morocco.
Figure 1 presents the location of the project. The study area contains different features; buildings, bare soil, trees, grass and streets.

Figure 1. Location of the study area (Google Earth, 2020)

2.2 Methodology

The purpose of this study is to assess the potential of drone airborne LiDAR technology in Morocco in comparison with drone photogrammetry. This study was motivated by the following reasons: (1) Limited number of studies in Morocco on drone-based LiDAR technology applications, (2) Lack of study on the parameters that influence the quality of drone-based LiDAR surveys as well as on the evaluation of the accuracy of derived products compared to drone photogrammetry. The cost and complexity of the equipment are among the causes limiting its use in Morocco.
The evaluation of this technology was done by an analysis of the geometric precision, the processing time of the 2D and 3D products generated in comparison with the products generated by drone photogrammetry. Before starting the data processing phase, classification of points cloud and digital model generation, several tests have been carried out to analyze the parameters that influence the quality of the results. The proposed methodology contains the following main steps:

a) Many drone-based LiDAR test survey missions are conducted, which allow us to analyze the main parameters that affect the results, namely the flight height, the speed of the drone and the scanning frequency of the laser scanner. 3D models will be generated from a mission with the adopted parameters.
The main steps in LIDAR mission are : Flight Planning (visit of the study area, assessment of weather and climate conditions, choice of flight parameters to be evaluated, planning of the shooting mission), Data Acquisition, Data preprocessing, LiDAR Data Processing (cleaning, consolidation, generation of mesh models, generation of basic derivative products, creation of 3D models, point cloud classification, point cloud texturing).

b) An aerial photogrammetry mission is carried out in the same area in order to obtain 3D models using drone photogrammetry techniques. An RGB camera is used. The main processing steps by drone photogrammetry are the followings: camera alignment, generation of dense point clouds, creation of meshes, generation of textures and finally creation of 3D models. This processing was done using Agisoft's Metashape software. A terrain mission was conducted using RTK-GNSS to survey Ground Control Points (GCPs) used for the georeferencing step.
The generation of the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) is obtained on the basis of a point cloud filtering to determine the points that will be used for the triangulation. An another determining factor is the resolution which must be adapted to the objectives of the project. The quality of the ortho-image depends directly on the quality of the DSM.
After the generation of the ortho-image, the restitution step was carried out by the use of computer-assisted drawing software. This operation requires a qualified operator and high pointing precision.
The reconstructed LiDAR-based and image-based 3D models are georeferenced using trajectory information provided by a survey-grade GNSS/INS unit onboard the drone (direct georeferencing)

c) A planimetric and altimetric comparison of the results obtained from the two missions compared to the results obtained using direct surveys by GNSS positioning systems. A comparison of the 2D and 3D products generated by lasergrammetry and drone photogrammetry was carried out, referring to a survey performed by GNSS positioning system of our test area. The evaluation was carried out by an analysis of the geometric accuracy of the derived products.

2.3 Equipment used

The experimentation was conducted using the Geo-MMS system, which is a product of Geodetics, embedded in the rotary wing hexa-copter Matrix M600 PRO with a ZENMUSE X5 Camera produced by DJI.
The Geo-MMS system is a fully integrated LiDAR mapping tool with the drone. Geo-MMS includes a Geo-iNAV inertial navigation system coupled to a LiDAR sensor. The raw data from the integrated GPS, IMU and LiDAR sensors, as well as the navigation data calculated by the system, is recorded on an internal recording unit. Once the mission is completed, the recorded data is pulled out of the unit for further processing.

The system combines the results of the navigation solution extracted from the IMU with the LiDAR point cloud and produces a georeferenced point cloud in LAS format.
The DJI Zenmuse X5 series is equipped with a 4/3'' CMOS RGB camera with a resolution of 16 Megapixels and a camera capable of filming in 4K (UHD 3840x2160 pixels) at 30 fps.

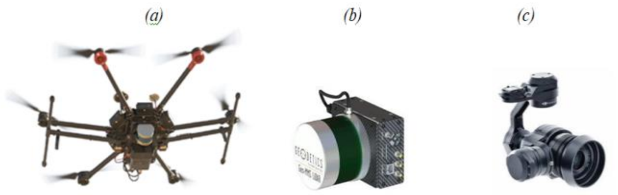

Figure 2. Equipement: (a) Drone DJI Matrice 600 Pro, (b) LiDAR Geo-MMS, (c) Camera ZENMUSE X5

2.4 Software used

To respond to the requirements of the processing chain, several software programs were used. For LiDAR data : Drone Deploy for Planning of drone missions, Lidar Tools and LASTools for LiDAR data preprocessing and point cloud visualization, LIDAR360 for the processing, classification and generation of derivative products from LiDAR data and Terra-Photo for point cloud texturing. For drone imagery we used Photoscan Pro for photogrammetry processing, ArcGIS for editing and preparing orthophotos. Finally, we used AutoCAD Map 3D for image restitution and edition of plans and Trimble Business Center for GNSS data processing.

3. RESULTS

For drone-based Lidar mission, several tests were carried out to analyze the parameters that influence the mission results. After data collection, the processing phase was carried out. It includes: the cleaning, the consolidation then the classification of point clouds and the generation of the various digital models.
After the step of georeferencing and the initial processing of point clouds acquired by the planned tests, processing, classification and generation of digital models were carried out in accordance with the proposed methodology. In the following sections, we will present the processing and the classification results obtained by the two missions of drone-based Lidar and drone photogrammetry. We will also present results of the geometric comparison of the products generated by the two technologies.

3.1 Parameters of LiDAR mission

Table 1 shows the parameters of the different tests carried out.
Two pulse frequencies were tested: 600 Hz and 900 Hz with variation in flight heights of 20, 40 and 50 m for each frequency. A total of six test missions were conducted. Two overlaps were tested (15% and 30%). The overlap of 30% was chosen. It ensures a minimal overlap to apply band alignment. If a large overlap is chosen, this will result in obtaining a double collection of objects resulting on an increasing of noise, especially if working with a very low height, a 180 degree field of view and a range of up to 70 m.

Test	**Pulse frequency (Hz)**	**Hight (m)**	**Density per m^2**
I.1		20	250
I.2	600	40	184
I.3		50	113
II.1		20	250
II.2	900	40	197
II.3		50	117

Table 1. Parameters of LiDAR mission

The analysis of the point cloud quality of the test flights performed shows the influence of the flight height, frequency and chosen overlap. The density of points per m2 of the various tests is greater than 100 points / m2 allowing a centimetre level resolution. The choice of the relevant survey for subsequent processing and geometric accuracy analysis was based on the amount of noise in the point cloud. Using a flight at a frequency of 900 Hz with, a height of 40m and overlap of 30% generates the least noisy point cloud with a density of 197 points per square meter. The following figure shows a capture of the point cloud obtained.

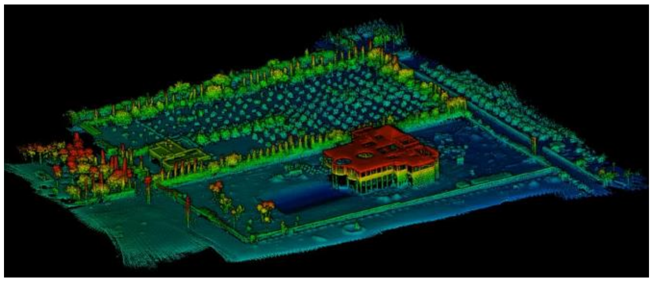

Figure 3. Point cloud of the study area obtained by Drone-based LiDAR

3.2 Presentation of products derived from the LiDAR mission

Generation of digital models

A low altitude airborne LiDAR point cloud generates a high density point cloud, and this has allowed us to have a high resolution DTM, DSM and DCM. The quality of these digital models depends on the precision of the classification of the point cloud.
For the generation of a digital terrain model, a classification of points on the ground is necessary. To do this, it is important to make a good choice of the iteration parameters and to perform a subsequent refinement using the tool for extracting midpoints on the ground. We opted for an iteration angle of 30 degree and a maximum distance equal to 1 m. The high density of points per m2, allowed us to generate a DTM with centimeter level resolution using the TIN method which is based on the DELAUNAY triangulation.
The generation of the DSM is done automatically based on the soil class to acquire the surface elevation. The generation of the DCM is done by a simple subtraction between the DSM and the DTM in vegetation area. The generation of the DCM of an urban area can generate errors due to the presence of buildings. A classification of the point cloud is mandatory. We generated another DSM with the same resolution without introducing the building class into the processing. The quality of the DCM depends directly on the generation quality of the DSM.

Point cloud classification

The classification of the point cloud is the most complicated step in terms of processing, given the complexity of the algorithms used depending on the characteristics of the surfaces scanned. The classification of the point cloud is carried out using two methods: by thresholding which requires manual intervention to classify each class by entering the necessary parameters (vegetation, soil, buildings, etc.). The other method is by machine learning algorithms. In our case, we used the Random Forest classification method. The machine learning classification reduces processing time and manual editing of the different classes while obtaining high quality results. The quality of classification depends on the training sample. The tests carried out show that a classification of points on the ground is essential as a preprocessing step, before starting the automatic classification. The final result was obtained by manual classification of the ground points as preprocessing, and Random Forest classification by referring to the classification by thresholding as training samples. Figure 4 presents the processing results.

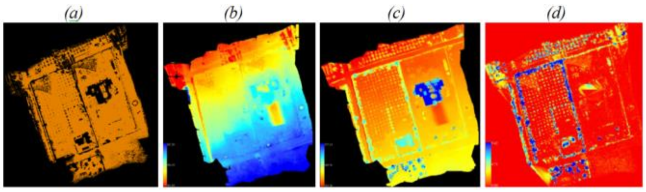

Figure 4. Processing Results of LiDAR Data: (a) Classification, (b) DTM, (c) DSM, (d) DCM

Establishment of the LiDAR restitution plan

The quality of a LiDAR restitution plan depends mainly on the point cloud classification step. The boundaries of houses and properties were perfectly clear given the density of the point cloud and the power of the classification algorithms. The figure below presents the restitution result superimposed on the Lidar point cloud.

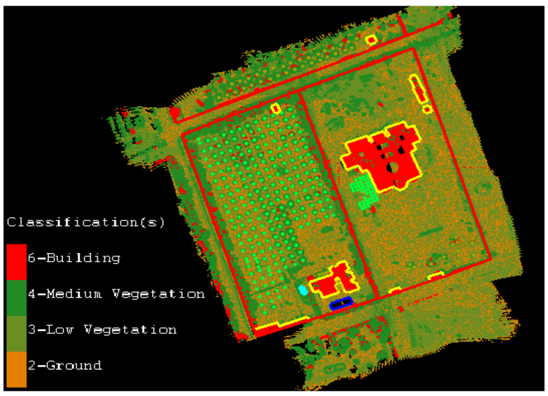

Figure 5. The restitution superimposed on the Lidar point cloud

In some regions of the study area, the absence of points is explained by the presence of a water surface; a swimming pool where no pulse is returned. The establishment of a restitution plan by LiDAR is a step that requires pointing precision by the operator. It allows drawing of large structures, buildings and object boundaries with very high precision, which proves the potential of this technology.

3.3 Presentation of products derived from drone imagery

Generation of a dense point cloud

The generation of a dense point cloud is the initial product of the photogrammetric processing. It requires cleaning of the noise due to an extrapolation of the reception of the light signal. The preprocessing quality impacts the generation of derivative products, namely the 3D model.
The principle of image correlation of the images makes it possible to generate a dense cloud of points. The presence of shadow on the swept area and on the facades of buildings can cause a lack of points. Figure 6 below shows the dense point cloud of the study area generated from drone imagery.

Figure 6. Dense point cloud of the test zone by drone photogrammetry

Generation of orthophoto

The processing was based on the DSM to produce a high resolution orthophoto (3 cm resolution). Figure 7 presents the orthophoto generated from drone imagery.

Figure 7. Orthophoto with a ground sample distance of 3cm

3.4 Evaluation of derived products

The quality of the drone-based LiDAR point cloud depends on the flight parameters, the characteristics of the material used and the parameters of processing. All these parameters generate systematic errors affecting the quality of the generated products. An assessment of was carried out to compare the geometric accuracy of the drone-based Lidar and drone imagery products.

Analysis of the results of the planimetric comparison

The first comparison made was based on determining the corners of existing buildings from LiDAR point cloud in the test area. The second comparison performed was based on a restitution of the corners on the orthophoto generated by drone photogrammetry. The reference survey was obtained by RTK-GNSS technique. After calculating the differences between the coordinates, an evaluation of statistical elements was established for a better understanding of the differences.
We established point correspondence between the RTK-GNSS check points (reference) and the LiDAR and drone imagery point clouds. Then, the coordinate differences between the point pairs are calculated. Mean deviation, Standard deviation, Minimum deviation and Maximum deviation are reported.
The table below presents the comparison result.

	LiDAR Data Deviation (m)	*Drone Photo Deviation (m)*
Mean deviation	0.02	0.03
Standard deviation	0.03	0.04
Absolute minimum deviation	0.01	0.02
Absolute maximum deviation	0.12	0.09

Table 2. Planimetric evaluation in comparison with the GNSS reference survey

The mean deviation obtained for Lidar point clouds is 2 cm. The maximum deviation is 12 cm. This analysis shows the potential of LiDAR technology and its high planimetric accuracy. The result can be explained by the detection precision of the roofs, the high density of the point cloud and the accuracy of the classification algorithms used. The result of this comparison shows tolerable deviations.

For drone photogrammetry, we obtained 3 cm for mean deviation and a maximum deviation of 10 cm. The analysis of statistical elements shows minimal deviations which can be explained by the ground resolution, the low flight height and the power of the algorithms used for the georeferencing of the images and for 3D models generation.
For 2D analysis, we obtained in our case study almost the same results for the two technologies (Drone-based Lidar and Drone imagery).

Analysis of the altimetry comparison results

The analysis of the altimetric quality of the products generated from the lasergrammetric and photogrammetric missions was carried out with comparison to the heights of a sample of 20 points distributed randomly in the study area. These check points ware determined using RTK-GNSS technique. The following table presets the result of the statistical analysis.

	Difference Z_Photo-GNSS (m)	*Difference Z_LiDAR-GNSS (m)*
Mean deviation	0.09	0.05
Standard deviation	0.10	0.06
Absolute minimum deviation	0.03	0.02
Absolute maximum deviation	0.17	0.18

Table 3. Altimetric evaluation

The analysis of the results shows an average difference with respect to the reference survey of 5cm for Lidar and 9 cm for drone imagery. Lidar gives better standard deviation than drone photogrammetry.
This result confirms the potential of airborne LiDAR technology by drone in the generation and production of 3D models.

Discussion

This study confirms the potential of drone-based Lidar and drone photogrammetry for projects requiring high precision. The results of our experimentations give assessments of the derived point clouds and digital models in urban and sub-urban area in Morocco. Similar results were obtained by previous studies applied in different contexts (Zhou et al., 2020; Shaw et al., 2019). The accuracy obtained allows these technologies to be used in surveying projects at a lower cost and within a short timeframe. With these technologies, it is easier to generate a set of derivative products with very good resolution and maximum information.
In the drone-based Lidar mission, we found difficulties at the planning step to determine the optimal height, the appropriate speed and the better pulse rate for data acquisition. To solve this problem, we carried out various tests with a variation of all these parameters. The quality of the products generated depends mainly on the initial processing carried out and the precision of classification applied. The generation of the digital models and the LiDAR restitution plan was assessed by a planimetric and altimetric comparison on check points distributed randomly over the study area. The result clearly demonstrates the high accuracy obtained and validates the inclusion of this technology for the production and generation of 2D and 3D digital models with centimeter resolution.
For the drone photogrammetry mission, the quality of the generated orthophoto depends on the quality of the produced DSM. Its accuracy depends on the parameters of the shooting mission, the precision of the ground control points used, the georeferencing step and other factors such as the characteristics of the camera, the calibration and the characteristics of the drone used. The result of the geometric comparison with the reference points clearly confirms the potential of drone photogrammetry technology in the generation of the various surveying products.

4. CONCLUSION

This study demonstrates the potential of the drone-based Lidar in comparison to drone photogrammetry. The accuracy obtained confirms that airborne Lidar can be used in many surveying and mapping operations carried out by conventional methods (GNSS, Total Station).
The simultaneous use of drone-based Lidar and Drone photogrammetry in the same project still requires extensive research. The requirements in overlap between the lines of flights differ between the two technologies. In drone photogrammetry, a large overlap is required so that the processing algorithm can have a maximum of matches between the pixels of the images. For Lidar, a low overlap is recommended in order to avoid noise generation.
This study validates a workflow for the preprocessing of data, the classification of point clouds and the generation of the digital models derived from the processing of LiDAR data acquired by drone and drone imagery.
Further investigations are underway to address the various constraints identified during the realization of our study.

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