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INTEGRATION OF UAV AND GIS IN THE GENERATION AND ANALYSIS OF URBAN INFRASTRUCTURE

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A B S T R A C T

This study focuses on the application of aerial photogrammetry techniques using drone-acquired data, aimed at generating thematic mapping of urban infrastructure. For this purpose, the DJI Mavic 2 Pro drone was used; flights were conducted at different altitudes with overlaps between 70% and 80% in an area of approximately 20 hectares, allowing the capture of a high number of high-resolution images (less than 10 cm). These images were processed using Pix4D Mapper software, which, through Structure from Motion and Multi-View Stereo techniques, generated an orthophoto and a dense point cloud. Subsequently, the data was filtered to discard elements not belonging to the ground, enabling the creation of Digital Elevation Models and Surface Models. The incorporation of control points using GPS-RTK and the use of tools such as QGIS and Fusion software ensured the production of highly precise outputs, as evidenced by a very low Root Mean Square Error. Based on these models, contour lines and thematic maps were generated, facilitating a detailed analysis of the infrastructure within the study area. The results demonstrate that the use of UAVs in conjunction with photogrammetry techniques is an effective and low-cost alternative to traditional methods, optimizing the update and accuracy of cartography, especially in areas with difficult access.

1. INTRODUCTION

The technological advancements of recent decades have improved cartography (Connor et al., 2016), enabling the generation of more accurate maps that can also be updated in shorter timeframes. The data required to produce maps or thematic cartography are obtained from field measurements, with direct methods such as altimeters, total stations, or GPS being commonly used, as well as indirect methods such as remote sensors (González-Jaramillo et al., 2018).

Satellite imagery has been widely used for many years due to its accessibility (Liang et al., 2013). However, it presents low spatial resolution and is often unsuitable for detailed studies due to various environmental factors (González-Jaramillo et al., 2018). Data acquisition can also be performed using Light Detection and Ranging (LiDAR) equipment, which emits an electromagnetic energy beam that bounces off the Earth's surface to capture positional and height information (González-

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Jaramillo et al., 2019). However, this technology remains restrictive due to its high cost.

Unmanned Aerial Vehicles (UAVs) have become widely available in the civil sector (Singh et al., 2023), overcoming limitations related to spatial, spectral, and temporal resolution, and introducing a new concept of high-resolution remote sensing (Otgonbayar et al., 2018; Dong et al., 2020; Koeva et al., 2018). One of the main advantages of UAVs is their ability to perform tasks in areas where manned missions would be difficult, impossible, or unjustifiable due to high costs (Burdziakowski et al., 2020).

UAV-based photogrammetry allows the collection of data over large areas in short timeframes at low costs and with high resolution (Dandar et al., 2018). Photogrammetric processing is carried out using Structure-from-Motion (SfM) and Multi-View Stereo (MVS) techniques (Dong et al., 2020). Through the sequential processing of aerial photographs, a dense point cloud is generated, which serves as the basis for producing various digital terrain models, such as Digital Elevation Models (DEM) (Kozmus et al., 2020).

2. MATERIALS AND METHODS

2.1 Study area

The study area was defined as the premises of the Universidad Técnica Particular de Loja (UTPL), located at coordinates 79°11′56″W, 3°59′12″S, in the north eastern part of Loja city. The area covers 20 hectares, featuring buildings taller than 15 meters constructed on plateaus at different elevations, along with green spaces and paved areas (Figure 1).

2.2 NTRIP and field data collection

For the collection of Ground Control Points (GCPs), the NTRIP station of the Instituto Geográfico Militar (IGM) located on the UTPL campus was used, with coordinates Lat: -3.963, Long: -79.173. The use of this station is governed by Resolution No. IGM-IGM-2020-0095-R, which establishes the following: Publish the License and issue the policies for the use of the Differential Correction Service through the NTRIP Protocol, granting users a free and non-exclusive right to utilize the information under this license (IGM, 2020).

The GCPs survey was conducted using an Emlid Reach GPS-RTK system, as shown in Figure 1. Additionally, a physical reconnaissance was carried out to identify potential obstacles before conducting the UAV flights.

2.3 UAV flights

Once the control points were established, aerial surveys were conducted over the study area using the DroneDeploy software, which facilitated flight planning and execution (Alfio et al., 2020; Howell et al., 2020. The flight missions were performed with a Mavic-Pro-2 UAV, a multi-rotor platform developed by DJI, equipped with an RGB camera (Alfio et al., 2020; Howell et al., 2020. Two flights were carried out at altitudes of 80 and 100 metres, with overlaps of 70% and 80%, respectively, at a speed of 8 m/s. The camera inclination was maintained at 70°. Under these conditions, the estimated Ground Sample Distance (GSD) ranged from 2 to 4 cm/pixel. The flights were conducted in an area with minimal obstacles at an altitude of 2151 metres above sea level.

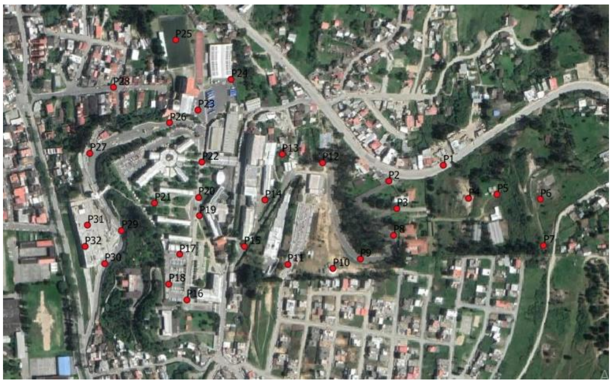

Figure 1. Location of ground control points (GCP) in the field

2.4 Methodology for digital models' creation and products

Pix4DMapper software was used to process the images through SfM and MVS approaches, generating sub-products such as point clouds, digital models, orthophotos, and contour lines. This software package enables 3D map reconstruction by combining aerial images captured by UAVs or conventional aircraft (González-Jaramillo et al., 2019).

The processing steps are detailed in (Dong et al., 2020). Key factors influencing model quality and accuracy include flight altitude and image overlap. The latter allows the software to identify common points across previously analysed photographs (Burdziakowski et al., 2020). To assess the accuracy of the outputs, the Root Mean Square Error (RMSE) index was used, calculated from verification points and UAV camera-derived data (Alfio et al., 2020; González-Jaramillo et al., 2019; Taddia et al., 2019).

For the generation of digital models from the point cloud, the open-source Fusion software was utilized (Mcgaughey, 2021), following these steps:

- Error correction in the Pix4D-derived point cloud using a standard deviation threshold of 3 and an action window value of 10 as recommended parameters.
- Filtering the point cloud to distinguish between Ground and Road Surface, with a minimum of 10 iterations.

- Creating a new point cloud with a resolution of 10 cm/pixel and cell filling between 300 and 350 to mitigate voids left by removed buildings.
- Generating a raster-based DTM from the processed point cloud.

With the obtained digital models and orthophoto, cartographic products were developed in QGIS software. The Digital Surface Model (DSM) enabled detailed mapping of buildings, whereas for the DTM, cell filling necessitated terrain corrections using the "Serval" plugin, allowing the creation of thematic maps such as contour lines and slope maps.

3. RESULTS

During the flights, three to four batteries were used per mission, and an average of 1000 high-detail aerial photographs were captured. Based on studies by Howell et al. (2020) and Kozmus et al. (2020), it was demonstrated that GSD values are influenced by flight altitude, with minimal variation in GSD for flights at the same altitude but different overlap settings, as shown in Table 1.

Due to the study area's varying elevations, flights encountered differences exceeding 120 meters. QGIS software performed interpolation to achieve a more consistent GSD across the study area, differing from flat terrain conditions. Howell et al. (2020) reported a GSD of 1.14 cm/pixel at 75 m altitude, whereas in this study, similar altitudes yielded GSD values above 2 cm/pixel.

Table 1. Obtained GSD values.

Altitude (m)	Overlap (%)	GSD (cm/pixel)
80	70	2.87
80	80	2.87
100	70	3.45
100	80	3.37

During the second stage of Pix4DMapper processing, it was observed that certain objects, such as rooftops, concrete surfaces, and vehicles, were automatically classified as Ground or Road Surface. To refine the DEM, these objects were manually reclassified.

A total of 97,785,401 points were obtained, with a density of 280 pts/m². After filtering the point cloud to retain only Ground and Road Surface data, 38,648,782 points remained, with a density of 111 pts/m². This refined point cloud was used to generate the DTM in Fusion software.

For the production of the orthophoto and contour lines, the Pix4DMapper software was used, as shown in Figure 2. The generated contour lines tend to produce terrain distortions, and the software also applies a smoothing algorithm, which prevents the terrain from being represented exactly as it is in reality.

Figure 2. Products Generated by Pix4D in high resolution

In Figures 3 and 4, the products obtained from the photogrammetric process are shown, where the high resolution of the drone photos allows for results of very high quality and acceptable products for use in projects.

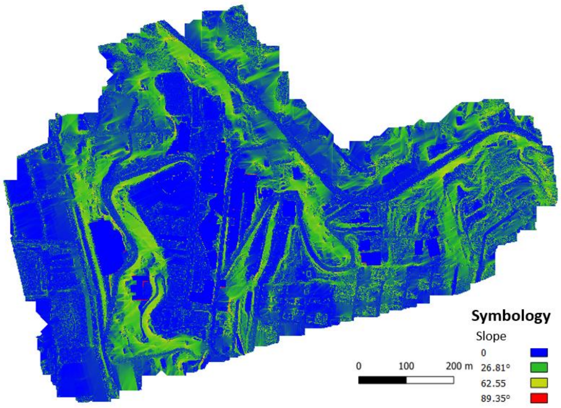

Figure 3. Contour lines of the research area

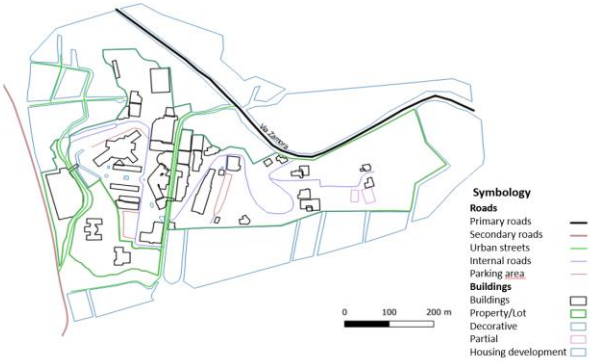

Figure 4. Representation of buildings in the research area

To evaluate the results (Purinton, & Bookhagen, 2017), it was calculated the RMSE, the value was estimated using verification points obtained by the UAV (Agüera-Vega et al., 2017; Sanz-Ablanedo et al., 2018; Yurtseven, 2019). A total of five verification points were collected; however, point P5, located near the flight perimeter, contained very limited information and was therefore excluded from the RMSE calculation. The results are shown in Table 2.

Table 2. Obtained GSD values.

Point	North (m)	East (m)	Height (m)	RMSE
P1	9559041.33	700225.40	2148.13	0.002372
P2	9559104.47	700588.81	2156.23	0.004033
P3	9559095.93	700001.44	2109.48	0.003019
P4	9558979.84	699814.63	2062.77	0.002616
RMSE (m)				0.027432

4. CONCLUSIONS

UAVs have revolutionized spatial data collection, enabling continuous data acquisition compared to traditional methods such as total stations or GPS, which are limited in the number of collected points and, consequently, the level of cartographic detail. In terms of spatial and temporal resolution, geographic data acquisition time, and operational costs, UAVs offer significant cost-benefit advantages over other surveying devices.

Image overlap has minimal influence on spatial resolution, with differences of less than 1 mm in this study. However, overlap should not be lower than 70%. Low-altitude flights enable the generation of ultra-high-resolution photogrammetric products, with resolutions below 1 cm per pixel.

This study confirms that UAVs provide a cost-effective alternative for thematic cartography, offering high-resolution data acquisition with reduced field personnel requirements and optimal results. However, ground control points remain essential for achieving high-accuracy outputs

References:

Alfio, V. S., Costantino, D., & Pepe, M. (2020). Influence of Image TIFF Format and JPEG Compression Level in the Accuracy of the 3D Model and Quality of the Orthophoto in UAV Photogrammetry. *Journal of Imaging*, *6*(5), 30. https://doi.org/10.3390/jimaging6050030

Agüera-Vega, F., Carvajal-Ramírez, F., & Martínez-Carricondo, P. (2017). Accuracy of digital surface models and orthophotos derived from unmanned aerial vehicle photogrammetry. *Journal of Surveying Engineering*, *143*(2), 04016025.

Burdziakowski, P., Specht, C., Dabrowski, P. S., Specht, M., Lewicka, O., & Makar, A. (2020). Using UAV photogrammetry to analyse changes in the coastal zone based on the sopot tombolo (Salient) measurement project. *Sensors*, *20*(14), 1–21. https://doi.org/10.3390/s20144000

Connor, D., Martin, P. G., & Scott, T. B. (2016). Airborne radiation mapping: overview and application of current and future aerial systems. *International journal of remote sensing*, *37*(24), 5953-5987. https://doi.org/10.1080/01431161.2016.1252474

Dandar, O., Okamoto, A., Uno, M., Batsaikhan, U., Ulziiburen, B., & Tsuchiya, N. (2018). Drone brings new advance of geological mapping in Mongolia: opportunities and challenges. *Mongolian Geoscientist*, (47), 53-57. https://doi.org/10.5564/mgs.v0i47.1063

Dong, X., Zhang, Z., Yu, R., Tian, Q., & Zhu, X. (2020). Extraction of information about individual trees from high-spatial-resolution UAV-acquired images of an orchard. *Remote Sensing*, *12*(1), 133. https://doi.org/10.3390/RS12010133

González-Jaramillo, V., Fries, A., Zeilinger, J., Homeier, J., Paladines-Benitez, J., & Bendix, J. (2018). Estimation of above ground biomass in a tropical mountain forest in southern Ecuador using airborne LiDAR data. *Remote Sensing*, *10*(5), 660. https://doi.org/10.3390/rs10050660

González-Jaramillo, V., Fries, A., & Bendix, J. (2019). AGB estimation in a tropical mountain forest (TMF) by means of RGB and multispectral images using an unmanned aerial vehicle (UAV). *Remote Sensing*, *11*(12), 1413. https://doi.org/10.3390/rs11121413

Howell, R. G., Jensen, R. R., Petersen, S. L., & Larsen, R. T. (2020). Measuring height characteristics of sagebrush (Artemisia sp.) using imagery derived from small unmanned aerial systems (sUAS). *Drones*, *4*(1), 6. https://doi.org/10.3390/drones4010006

IGM. (2020). Portal Geodesia | Liberación de Datos NTRIP. Retrieved from http://www.geoportaligm.gob.ec/geodesia/index.php/liberacion-de-datos-ntrip/

Koeva, M., Muneza, M., Gevaert, C., Gerke, M., & Nex, F. (2018). Using UAVs for map creation and updating. A case study in Rwanda. *Survey Review*, *50*(361), 312-325. https://doi.org/10.1080/00396265.2016.1268756

Kozmus Trajkovski, K., Grigillo, D., & Petrovič, D. (2020). Optimization of UAV flight missions in steep terrain. *Remote Sensing*, *12*(8), 1293. https://doi.org/10.3390/rs12081293

Liang, S., Li, X., & Wang, J. (2013). Advanced Remote Sensing: Terrestrial Information Extraction and Applications. *International Journal of Remote Sensing*, *34(*14), 5262–5263.

Mcgaughey, R. J. (2021). FUSION/LDV: Software for LIDAR Data Analysis and Visualization. USDA.

Otgonbayar, D., Atsushi, O., Masaoki, U., Batsaikhan, U., Ulziiburen, B., & Tsuchiya, N. (2018). Drone brings new advance of geological mapping in Mongolia: Opportunities and challenges. *Mongolian Geoscientist*, *47*, 53–57. https://doi.org/10.5564/mgs.v0i47.1063

Purinton, B., & Bookhagen, B. (2017). Validation of digital elevation models (DEMs) and comparison of geomorphic metrics on the southern Central Andean Plateau. *Earth Surface Dynamics*, *5*(2), 211–237. https://doi.org/10.5194/esurf-5-211-2017

Sanz-Ablanedo, E., Chandler, J. H., Rodríguez-Pérez, J. R., & Ordóñez, C. (2018). Accuracy of unmanned aerial vehicle (UAV) and SfM photogrammetry survey as a function of the number and location of ground control points used. *Remote Sensing*, *10*(10), 1606. https://doi.org/10.3390/rs10101606

Singh, C. H., Mishra, V., & Jain, K. (2023). High-resolution mapping of forested hills using real-time UAV terrain following. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *10*, 665-671. https://doi.org/10.5194/isprs-annals-X-1-W1-2023-665-2023

Taddia, Y., Stecchi, F., & Pellegrinelli, A. (2019). Using DJI Phantom 4 RTK drone for topographic mapping of coastal areas. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 625-630. https://doi.org/10.5194/isprs-archives-XLII-2-W13-625-2019

Yurtseven, H. (2019). Comparison of GNSS-, TLS-and different altitude UAV-generated datasets on the basis of spatial differences. *ISPRS International Journal of Geo-Information*, *8*(4), 175. https://doi.org/10.3390/ijgi8040175

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