Journal of Engineering Applications December 2024 Vol.11 No.32 26-35
Article

Methodological proposal for the topographic use of UAV compared to the use of traditional methods

Propuesta metodológica para el uso topográfico de UAV respecto al uso de métodos tradicionales

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[d] Tecnológico Nacional de México/TES Valle de Bravo • LIO-8300-2024 • 0009-0001-4680-224X • 2063155

CONAHCYT classification:

Area: Physics-Mathematics and Earth Sciences
Field: Earth and space sciences
Discipline: Geography
Subdiscipline: Topographic geography

https://doi.org/10.35429/JEA.2024.32.11.26.35

History of the article:
Received: September 01, 2024
Accepted: December 26, 2024

Check for updates

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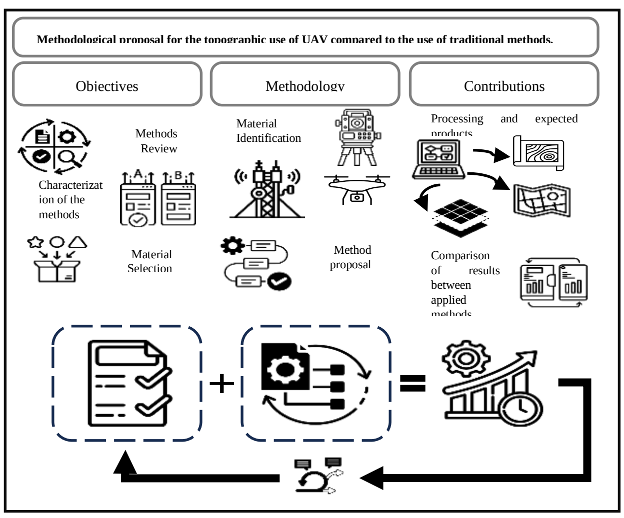
Abstract

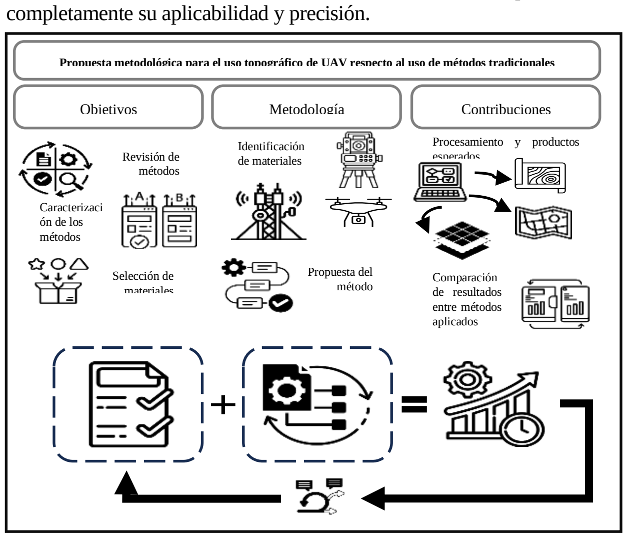
A methodology for topographic surveys using a UAV is presented, conducted at the Tecnológico de Estudios Superiores de Valle de Bravo (TESVB) with a DJI Phantom 4 Pro RTK drone, DJI GNSS DRTK2 mobile station, and Agisoft Metashape software. The objective is to propose an effective and precise methodology compared to traditional methods. The simplified approach allows for accurate position and processing information, generating digital terrain models. The results offer an efficient alternative, reducing time by 46.66% with a relative error of 0.64% in linear measurements and 0.42% in area measurements. Additionally, the UAV's ability to access various areas and capture real-time data is a significant advantage. This study demonstrates the potential of UAVs in topographic applications, although further analysis in different environments is necessary to fully validate their applicability and accuracy.



Methodological, Topographic, Unmanned

Resumen

Se presenta una metodología para levantamientos topográficos con un UAV, realizada en el Tecnológico de Estudios Superiores de Valle de Bravo (TESVB), utilizando un dron DJI Phantom 4 Pro RTK, estación móvil DJI GNSS DRTK2 y el software Agisoft Metashape. El objetivo es proponer una metodología eficaz y precisa comparada con métodos tradicionales. El enfoque simplificado permite obtener información precisa de posición y procesamiento, generando modelos digitales del terreno. Los resultados ofrecen una alternativa eficiente, reduciendo el tiempo en un 46.66% y con un error relativo del 0.64% en medidas lineales y 0.42% en el área. Además, la capacidad del UAV para acceder a diversas áreas y capturar datos en tiempo real es una ventaja significativa. Este estudio demuestra el potencial de los UAV en aplicaciones topográficas, aunque es necesario un análisis adicional en distintos entornos para validar completamente su aplicabilidad y precisión.



Metodológico, Topografía, No tripulado

Citation: Rodríguez-González, José Miguel, Gómez-Arizmendi, Gabriela, Velázquez-García, Jennyfer and Carranza-Reyes, Roberto. Methodological proposal for the topographic use of UAV compared to the use of traditional methods. Journal of Engineering Applications. 2024. 11-32: 26-35.

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Introduction

Surveying is an essential component of civil engineering. Its theory is mainly based on plane geometry, space geometry, trigonometry and mathematics in general.

Several authors define topography as the science through which positions of points located on the earth's surface, above and below it, can be established; therefore, measurements such as linear and angular distances and elevations are carried out (Mark & Smith, 2004; Rincón Villalba, et al., 2017).

Although the conceptualisation of topography has not changed over the years, the techniques, instruments and methods of application have been modified and increased, all generated by technological progress, from the use of the tape measure, theodolites and the total station.

Technological advances have revolutionised the way in which surveying is carried out, allowing accurate and detailed data to be obtained more efficiently. Particularly the use of Unmanned Aerial Vehicles (UAVs) has gained popularity for their ability to collect data in difficult to access areas and their versatility in generating three-dimensional terrain models (Remondino, et al., 2011; Westoby, et al., 2012).

Ground survey methods have undergone a complete transformation, keeping the accuracy of the product comparable to that of field surveys (Bangen, et al., 2014). High accuracy is not feasible even with digital aerial surveys due to flight height limitations. Technically, UAVs can fly virtually anywhere. Due to their high flexibility, the location of the platform and its viewing angle can be changed in a short time (Lyu, et al., 2023). Even with low-cost commercially available UAVs, flying at low altitudes is no longer a problem for the photogrammetry user community (Kršák, et al., 2016).

Thus, it is possible to obtain images with very high Ground Sampling Distance (GSD), close to 1 cm, which allows users to achieve remarkable positional accuracy without much effort.

Although low-cost drones are used in topographic surveys, there is still debate as to which platform, hardware and software are best suited to achieve the accuracy required for high quality surveys. With a sufficient number of accurate Ground Control Points (GCPs) and an on-board Real Time Kinematic (RTK) Positioning system with an accurate Inertial Measurement Unit (IMU), the desired accuracy can be easily achieved (Famiglietti, et al., 2024; Martinez-Fernandez, et al., 2024).

GCPs should be carefully selected, well distributed and visible in multiple images. Moreover, they must be easily identifiable in the images obtained.

On the other hand, with Unmanned Aerial Systems (UAS), the recurrent data acquisition that many studies require can be performed at any time. This is, of course, not possible with super-high-resolution satellite imagery that has a fixed temporal resolution. This is another factor contributing to the popularity of UAS (Awasthi, et al., 2020).

Some of the best classified methodological developments contain structures that do not depend on the software used but on the techniques employed, i.e. to scan a large area of land, such as a topographic map, a similar methodology is applied as developed with traditional methods, except that the photos would form a 'blanket' over the extent of a balloon site. Such forms of photogrammetry are usually carried out using UAVs. A topographic survey and mapping using photogrammetry has been gaining popularity due to its competitiveness; fast result, low cost and high accessibility (Lim, et al., 2021).

The techniques to be used and methods developed depend on the type of applicability, which is why the precise definition of a methodology is complex, as it depends on the context, equipment and even the experience of the practitioners (Rus, et al., 2024).

Background

With the variety of products on the market today, it is difficult to define a specific methodology, as there are different variables that determine it, the literature has interesting proposals;

ISSN: 2410-3454.
RENIECYT-CONAHCYT: 1702902

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Wu, et al. (2020) reported a process that includes the steps; 1) flight range determination, 2) obtaining control points, 3) aerial point installation, 4) flight plan simulation, 5) flight mission, 6) photo classification, 7) photo scanning and 8) layer fitting. This is without reporting the type of drone and software used.

Karakiş, et al. (2020) writes an ambiguous but effective method, which consists of; 1) identification of the study area, 2) flight planning, 3) data processing and 4) data correction. He uses an octocopter with a Canon EOS 450D camera and does not report the software used in the processing.

Devoto, et al., (2020) carried out a process in which they describe 3 general phases that include stages; I) Data collection, II) Post processing (Control points, 3D Models, DEMs and Orthomosaics) and III) Digitisation and data storage (map and image characterisation), using a DJI Mavic drone and with the use of two softwares Agisoft Metashape and QGIS.

Cortes Ospina (2021) proposes 4 phases; flight planning, ground support, photographic registration, image processing and calculations, using a 6-propeller multi-helicopter with a Canon EOS M camera and Agisoft Photoscan processing software.

Hao et al., (2023) outlines the following steps; 1) site survey, 2) UAV route planning, 3) flight height, speed and overlap rate adjustment, 4) ground control point (GPS) layout, 5) aerial photography, image collection, 6) image processing, 3D point cloud modelling, 7) discontinuity extraction and 8) accuracy verification. Using a DJI Matrice 300 RTK drone and GeoSMA-3D processing software.

Astor, et al. (2023), by means of an analysis to know the conditions of the working pavement by means of; 1) problem identification (drone flight on the road), 2) definition of potential solutions (3D model by means of image capture), 3) behaviour study (Study of the images) and 4) analysis and evaluation (Statistical evaluation and comparison with conventional methods). A DJI Phantom 4 Pro drone, geodetic GPS and Agisoft Methashape software were used in the study.

Wang, et al. (2023), in their reported work for bridge risk analysis opts for the phases of; 1) flight plan, 2a) 3D reconstruction, 3a) visualisation of geometric variables, 4a) capacity model, 4a.a) demand model, and 2b) location, 3b) safety verification and 4b) seismic hazards. Using a DJI Mavic 2 Pro drone and Agisoft Metashape Software

Dmytro Stelmakh, et al. (2024), the methodology he writes deals with the reconstruction of a structure takes a method based on; a) flight plan, b) taking photographs, c) analysis of photographs and detection of defects, d) construction of the 3D model and e) recommendation of the defects found. Using a DJI AIR 2S drone and 3DF Zephyr software.

On the other hand, Siafali & Tsiorias (2024), in their study using UAVs present an approach for surface deformation estimation in road and forest trail networks, using a fixed-wing SenseFly eBee drone, mounted with a 3D S.O.D.A. camera and using PIX4Dmapper software, where they propose; 1) area survey, 2) flight planning, 3) data collection, 4) data processing and model generation.

In a comparative study of sensors, recently in Italy Ciccone et al. (2024), carried out a survey study of an archaeological site, where they compared the use of multispectral sensors mounted on two drones; a DJI Phantom Multespectral drone and a DJI Mavic Enterprise Advanced drone, using the PIX4D Field software, were able to obtain images in different seasons of the year and thus have a survey study with a substantial amount of data.

Materials and Method

In the quest to propose a method that is based on the context of conducting the survey, this work represents a technological advance that enters into the revolution of the way topographic surveys are conducted, marking a significant difference with the methods of the 'past'. Previously, topographic surveys were first carried out with tape-measure measurements. Then, with technological advances, the theodolite appeared, and finally the total station was introduced. In this field, the DJI Phantom 4 Pro RTK drone (Figure 1) has emerged as a tool in geospatial data capture, thanks to its centimetre accuracy and its ability to integrate Global Positioning Systems (GPS) and satellite navigation.

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Box 1

Figure 1
Dron DJI Phantom 4 RTK with remote control

The DJI DRTK 2 GNSS mobile antenna (Figure 2) was also used, which provides real-time differential data, allowing centimetre-accurate positioning to be achieved. The integrated high gain antenna ensures better reception of signals from multiple satellites, even in situations where the signal is obstructed.

Box 2

Figure 2
Mobile antenna GNSS DJI DRTK 2

On the other hand, we can combine these tools with the features of Agisoft Metashape image processing software, which has proven to be an effective solution for the generation of detailed and accurate topographic models from aerial images.

The purpose of the study is to present a complete methodological proposal for conducting topographic surveys using the DJI Phantom 4 Pro RTK drone, the DJI DRTK 2 GNSS mobile antenna and the Agisoft Metashape software. It should be clarified that the decision was taken to compare the measurements made with a Sokkia iM-50 total station because of the lack of the original plans and otherwise because there are no.

Box 3

Figure 3
Sokkia iM-50 Series Total Station

The DJI Phantom 4 RTK is a drone specifically designed for professional applications in surveying and mapping, precision agriculture, disaster management and environmental research. It features RTK integration that provides centimetre accuracy, making it ideal for work that requires high accuracy in geospatial data collection. (Taddia, Stecchi, 2019).

Box 4
Table 1
DJI Phantom 4 RTK Drone Technical Specification

Technical characteristics	Specification
RTK positioning system	This system allows a horizontal accuracy of 1 cm + 1 ppm (parts per million) and a vertical accuracy of 1.5 cm + 1 ppm, which is significantly higher than conventional GPS systems.
Camera and sensor	1-inch, 20-megapixel CMOS sensor, providing high-resolution (FHD) images. The mechanical shutter eliminates rolling shutter distortion, ensuring clear and accurate images are captured, even when the drone is in motion.
Mapping accuracy	It can generate 3D maps and orthomosaics with aerial survey accuracy,
Flight time	offers a maximum flight time of approximately 30 minutes.
Compatibility with base stations	Compatible with DJI's D-RTK 2 mobile station, which provides real-time differential data for even greater accuracy. In addition, it can be used with RTK NTRIP (Network Transport of RTCM - Internet Protocol) networks to extend its versatility in different environments.

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The DJI DRTK 2 mobile GNSS antenna is a high-precision base station designed to provide real-time differential data to drones and other navigation equipment. This antenna is compatible with a wide range of DJI drones, including the Phantom 4 RTK, Matrice 300 RTK, and other models, allowing them to improve the accuracy of their positioning systems (Taddia, González-García, 2020).

Box 5

Table 2

DJI DRTK 2 GNSS Mobile Antenna Technical Specification

Technical characteristics	**Specification**
Positioning accuracy	Horizontal: 1 cm + 1 ppm Vertical: 2 cm + 1 ppm
Constellations GNSS	GPS: L1, L2 GLONASS: F1, F2 BeiDou: B1, B2 Galileo: E1, E5a
Update frequency	1 Hz, 2 Hz, 5 Hz, 10 Hz, 20 Hz
Communication interface	UART Ethernet OcuSync Wifi 4G
Environmental resilience	Degree of protection IP57 (dust and water) Operating temperature:-20°C-55°C
Compatibility	Drones DJI: DJI Phantom 4 PRO RTK, Matrice 300 RTK Con redes NTRIP (Network Transport of RTCM – internet protocol).

The professional Agisoft Metashape software works for photogrammetric processing of digital images and the generation of 3D geospatial data. It is designed to convert 2D images into accurate three-dimensional models, enabling advanced applications in various fields.

The selected terrain is the esplanade of the Tecnológico de Estudios Superiores de Valle de Bravo, located in the municipality of Valle de Bravo, State of Mexico, Mexico, (Figure 4) coordinates (19°14'18 'N 100°07'53 'W). The terrain definition is shown in Figures 4 and 5, taken using Google Earth.

Box 6

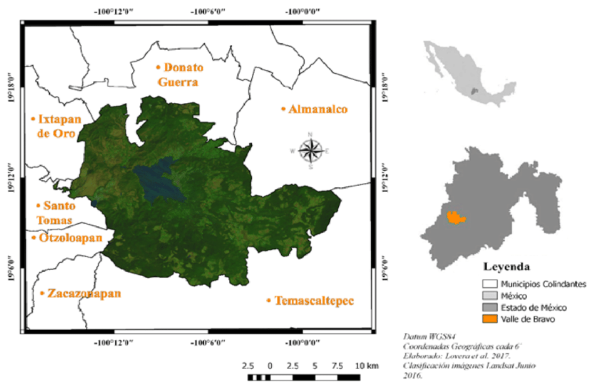

Figure 4

Location of the study site, location of the municipality in the State of Mexico

Box 7

Figure 5

Location of the study site; Tecnológico de Estudios Superiores de Valle de Bravo

Box 8

Figure 6

Location of the study site; exact location within the TESVB

After locating the terrain, a topographic survey was carried out by means of the conventional method using the reported total station, as shown in Figure 7.

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Box 9

Figure 7
Carrying out the topographic survey with the total station

Based on the formulation, context and team, the methodology described in Figure 8 is proposed, where we observe the following phases:

Box 10

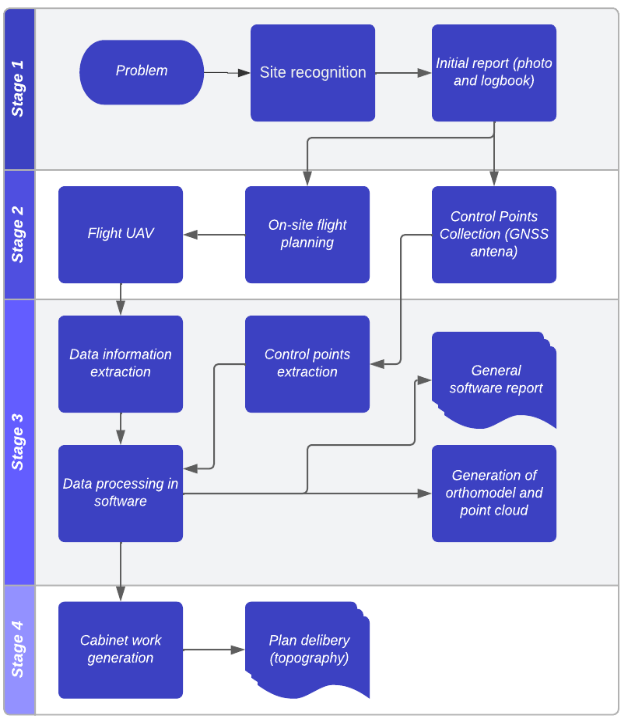

Figure 8
Proposed methodology for surveying with the use of UAV technology

Stage 1

Problem. The justification for the study is defined and the initial measurement parameters are established.

Site reconnaissance. A detailed analysis of the site is carried out, considering the general characteristics of the terrain that will determine the process to be followed.

Initial report. A photographic report of the site is prepared, documenting the characteristics observed.

Stage 2

Taking of control points (GNSS). This process is crucial for the processing and reference of the project.

On-site flight planning: Based on the terrain characteristics, the UAV flight is planned to optimise data collection.

UAV flight: The flight is carried out following the established planning, monitoring any possible inconvenience.

Stage 3

Extraction of control points: The necessary information is collected using the GNSS antenna and the UAV.

Data extraction: The data collected by the UAV is extracted for further processing.

Data processing in software: With the control points and flight data, the data is processed in specialised software.

General software report: A detailed processing report is generated according to the specific characteristics of the project.

Orthomodel and point cloud generation: From the report, the ortho-model and point cloud are extracted to produce the topographic plan.

Stage 4

Generation of the cabinet work: Stakeout work is carried out to generate the final deliverable.

Delivery of plans (topography): Finally, the topographic plans are delivered, ready to be used according to the user's requirements.

Following the aforementioned stages, the terrain survey was carried out using the described materials. The terrain survey is shown in Figure 6, followed by the survey of control points (Figure 9) and flight planning, as shown in Figure 10. A 3D flight was chosen to detect possible irregularities in the terrain, leaving the default settings in the system for this study.

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Box 11

Figure 9
Taking of control points with GNSS mobile stations

Box 12

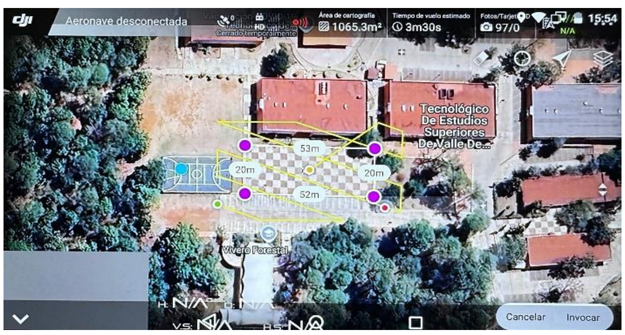

Figure 10
Flight planning, as seen from the UAV control

Subsequently, after the extraction of control points and data, they were processed in specialised software to obtain final products such as the orthomodel and the point cloud. With this information, cabinet work was carried out to generate the polygon plan with the extracted topography. Results and discussion The plan made by the conventional method (Figure 11) allowed the extraction of time data (Table 4) and the reference of the plan. In addition, 3 people worked on it.

Box 13

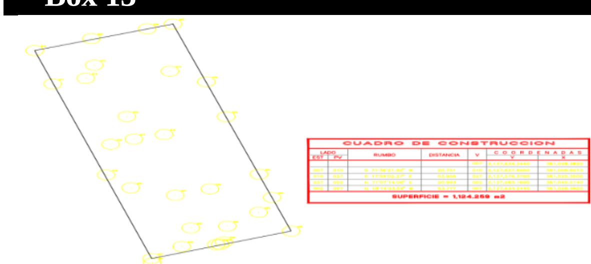

Figure 11
Terrain polygon made with the survey using the total station

Box 14

Table 3
Working time data for each activity in the survey using the total station

Activity	Working time
Survey	90 min.
Processing	20 min.
Cabinet work	40 min.
Total time	150 min.

On the other hand, for the UAV survey, the ortho-model, the point cloud, the polygon generated from the data collection (Figures 12, 13 and 14), together with the working times (Table 4), are presented.

Box 15

Figure 12
Orthomodel enhanced in Agisoft Metashape software

Box 16

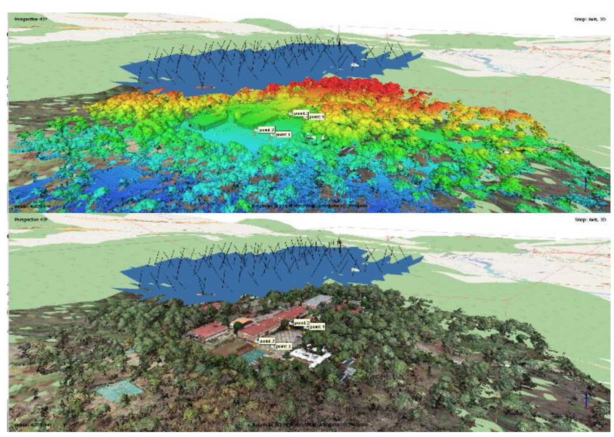

Figure 13
Dense point cloud, showing terrain elevation and photogrammetric elevation

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RENIECYT-CONAHCYT: 1702902

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Box 17

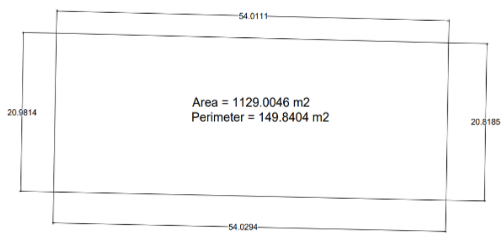

Figure 14
Polygon generated from UAV survey

Box 18

Table 4
Data on the working time of each activity in the UAV survey.

Activity	Tiempo de trabajo
Survey	10 min.
Processing	40 min.
Cabinet work	20 min.
Total time	70 min.

According to Tables 3 and 4, a time reduction of 46.66% is observed compared to the use of the total station. In terms of accuracy, the average relative percentage error of the length of each side of the polygon is 0.64% and the relative percentage error of the area taken is 0.42%, which indicates that the process is relatively efficient, as we have a relative percentage error of less than 1%.

The final products are suitable for end-user use, meeting the requirements of accuracy and usability.

The process is concrete and follows clear steps; however, further testing on more rugged terrain is suggested to assess the capability of the methodology under various conditions.

Conclusions

The proposed methodology is effective for surveying in terrain similar to the one studied, where the topography is not very rugged. However, there is a need to improve the capture of control points in a more efficient way, since, in larger areas or terrain with greater relief, the process may vary due to the processing capacities required.

On the other hand, the time needed to obtain the ortho-model is significantly reduced, which facilitates the creation of a virtual model applicable in several areas beyond topography. Finally, it is worth mentioning that the methodology fulfils the objective of providing a tool applicable to topographic surveys, although it poses the challenge of improving and testing it in different contexts.

Declarations

Conflict of interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Rodríguez-González, José Miguel: Contributed with the original idea, planning of activities and formulation of the proposed methodology.

Gómez-Arizmendi, Gabriela: Worked with the time management of activities, topographic surveys, flight plans and in the analysis of results and calculation of errors.

Velázquez-García Jennyfer: Undergraduate student who contributed to the characterization of equipment, flight planning and execution, as well as data classification with the drone.

Carranza-Reyes, Roberto: Undergraduate student, who worked on the topographic survey with a total station and drone, generating the technical data for the project.

Availability of data and materials

The data generated are in the custody of the Tecnológico Nacional de México9/TES Valle de Bravo, where they can be made available on request to the corresponding author's email address.

Funding

No external funding was received for the research, it was carried out with resources and funds from the Institute itself.

Acknowledgements

The authors are grateful to the Tecnológico de Estudios Superiores de Valle de Bravo for their support during the development of this work.

Abbreviations

DEMs	Digital Elevation Model
GCP	Ground Control Point
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GSD	Ground Sampling Distance
IMU	Inertial Motion Unit
RTK	Real Time Kinematics
TESVB	Tecnológico de Estudios Superiores de Valle de Bravo
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle

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ISSN: 2410-3454.
RENIECYT-CONAHCYT: 1702902