Determination of the international pavement regularity index through unmanned aerial vehicles

Determinación del índice internacional de regularidad del pavimento a través de vehículos aéreos no tripulados

[Norys Haiddy] [Peña Ramirez], [Omar Javier] [Jiménez Jiménez], [Juan José] [Alarcón] & [Eliana] [Bohorquez]

[Ingeniería Civil], [Universidad Pedagógica y Tecnológica de Colombia], [Colombia], [norys.pena@uptc.edu.co]

ABSTRACT: This research presents a workflow for the inspection of flexible pavements in urban areas, obtained through Unmanned Aerial Vehicles (UAV). The processing of the data collected using specialized software, permits the generation of products such as the point cloud, the digital surface model (DSM) and the orthophoto, whose analysis allows extracting information of the road infrastructure, in this case, the International Roughness Index (IRI). The results obtained denote an acceptable level of applicability for the flow and the equipment used, by providing continuous and accurate information for the elaboration of reports on the surface condition of urban roads. At the same time, the applied method shows a high practicality of use, since it allows the periodic collection of information by the competent authorities, or to extract new data from the same information when different processes are carried out. All this information allows the creation of databases, follow-up plans, maintenance and rehabilitation of urban roads.

KEYWORDS: UAV, Pavement, Infrastructure, index

RESUMEN: La presente investigación expone un flujo de trabajo para la inspección de pavimentos flexibles en zonas urbanas, obtenido a través de Vehículos Aéreos no Tripulados (UAV). El procesamiento de los datos recolectados a través de software especializado, permite la obtención de productos como la nube de puntos, el modelo digital de superficie (DSM) y la ortofoto, cuyo análisis permite extraer información de la infraestructura vial, en este caso, del Índice de Rugosidad Internacional (IRI). Los resultados obtenidos denotan un nivel de aplicabilidad aceptable para el flujo y el equipo empleado, al otorgar información continua y precisa para la elaboración de estudios que den cuenta del estado superficial de las vías urbanas. A su vez, el método aplicado evidencia una alta practicidad de uso, ya que permite la recolección periódica de información por parte de las autoridades competentes, o bien, extraer nuevos datos de la misma información al realizar diferentes procesamientos. Toda esta información permite crear bases de datos, planes de seguimiento, mantenimiento y rehabilitación de vías urbanas.

PALABRAS CLAVE: UAV, Pavimento, Infraestructura, Índice

1 INTRODUCTION.

Roads are the main road assets managed by the State. This infrastructure is essential for the socioeconomic development of the country, as it allows the movement of goods, people and services (Herra 2018). To carry out these activities, the roads must meet functional, safety and comfort standards, as a result of constant monitoring, maintenance and rehabilitation actions (Kashiyama et al. 2020).

In Colombia, the regulations related to the construction, monitoring, maintenance and administration of road assets are issued by the Instituto Nacional de Vías (INVIAS 2016, INVIAS 2006). Within these aspects, the entity uses technical, structural and functional evaluation to monitor the road infrastructure. Part of the functional evaluation corresponds to the determination of pavement surface conditions and their respective indices.

Because of this evaluation, it is possible to correlate elements of the pavement's structural condition according to the damage's type and severity (De Solminihac et al. 2019). Another application of the results obtained is the creation of behavioral models, whose purpose is to predict the effects of maintenance activities and their relationship with the quality assurance of functionality indicators.

In the international context, UAVs and the application of artificial intelligence techniques have made it possible to automate auscultation processes (Wang & Ye 2022, Chun et al. 2021, Zhang et al. 2020, Gopalakrishnan 2018, Gui et al. 2018, Hoang 2018, Pan et al. 2018, Yousaf et al. 2018). On the other hand, the implementation of complementary technologies such as Light Detection and Ranging (LiDAR), and high-resolution cameras have increased the accuracy of the information, widening the fields of action (Tan & Li 2019, Ragnoli et al. 2018). Thus, the implementation of UAVs has demonstrated acceptable applicability thanks to their technical and economic feasibility in obtaining road information.

2 MATERIALS AND METHODS

2.1 *Study area*

The study area corresponds to an urban road, located in the city of Tunja, Boyacá, inside the facilities of the Universidad Pedagógica y Tecnológica de Colombia as shown in Figure 1. This corridor is 87 meters long, has an asphalt pavement, and connects important buildings of the educational institution, with an average daily traffic of approximately 200 vehicles.

Figure 1. Study area

2.2 *Flight mission*

This stage includes flight planning activities and the determination of the optimal conditions for data collection. The parameters were extracted from the recommendations of similar studies as (Atencio et al. 2022, Romero-Chambi et al. 2020).

The flight mission was carried out using Dronedeploy, which allows for delimiting the study area and establishing flight parameters. The application automatically sets the flight lines, number of images, ground sampling distance (GSD), and approximate time of flight as shown in Figure 2.

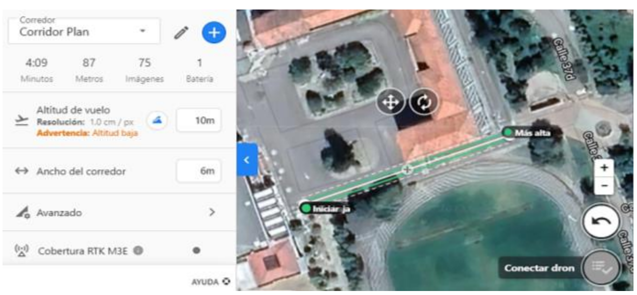

Figure 2. Flight mission configuration through the Dronedeploy application.

Similarly, Ground Control Points (GPC) were established in a homogeneous way.

These elements increase the precision of the final products (Ferrer-González et al. 2020).

2.3 *Image acquisition*

The second stage includes the completion of the flight, where the aerial images were collected. The equipment used corresponds to a DJI drone, Air S2 model equipped with camera, battery and gimbal, whose characteristics are presented in Table 1.

According to the requirements of the study, it was decided to carry out automatic flights where the drone follows the route previously established in the flight mission, as shown in Figure 2, and captures the images following the parameters presented in Table 2.

Table 1. Drone characteristics

Equipment	*Parameter*	*Value*
Battery	Capacity	3750 mAh / 3500 mAh
	Battery life	6 h
Camera	Sensor Size	1" CMOS
	Total effective pixels	20 megapixels
	Aperture	f/2.8
	Focal length	35 mm
Gimbal	Stabilization	3 axis (tilt, roll, pan)

Table 2. Flight configuration

Parameter	*Value*
Front overlap	75%
Lateral overlap	65%
Speed of flight capture	7 m/s

The combination of these parameters allowed the realization of flights that respond to the needs of the study, and its authors, by obtaining high quality photographs in practical procedures.

2.4 *Image processing*

At this stage, photographic processing was carried out with Agisoft Metashape photogrammetry software, a computer with a 2.4 GHz Intel5 processor and 8 GB of RAM memory, and a set of images. By entering and processing the photos in the mentioned software, point clouds, digital surface models (DSM) and orthophotos were obtained for each zone.

Following this, data extraction from the digital elevation model was performed through the sequential development of tools that automate the process in the ArcMap software. This allowed the graphical and numerical obtaining of the irregularity profiles for the studied road.

Finally, the IRI was calculated according to the sampling range (Badilla 2011, Sayers 1995) and ProVAL software modules. In this program it was necessary to define the type of analysis and indexes to be implemented, data segmentation and evaluation limits, as shown in Table 3.

Table 3. ProVal Software Parameters

Parameter	*Value*
Analysis Type	Fixed Interval
Ride Quality Index	IRI
Threshold (m/km)	4,7
Segment Length (m)	2,0

The evaluation limit used is based on the considerations presented by Strategic Highway Research Program, Manual for profile measurement: Operational field guidelines 1994, where it is stated that values of 4.7 m/Km (300 in/mil) or more are considered rough and uncomfortable. Thus, the final reports and results were obtained for the subsequent evaluation.

In general, the workflow developed in the methodology is presented in Figure 3

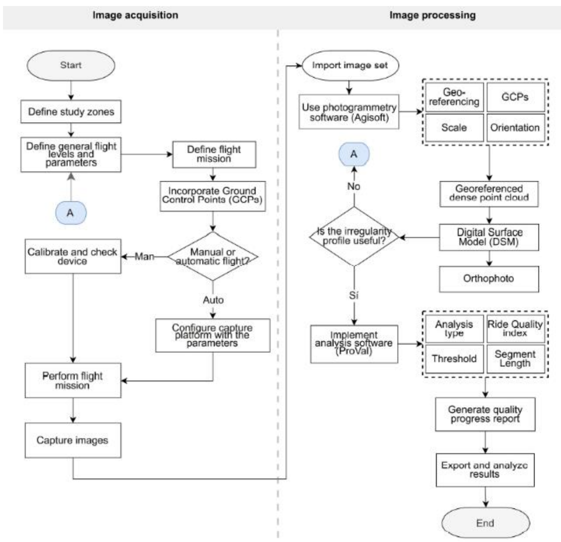

Figure 3. Workflow

3 RESULTS

From 76 images captured in stage 2 and the processing performed in stage 3, three final products were obtained: a point cloud, a digital elevation model, and an orthomosaic.

In the first case, a cloud composed of more than 15 million densified points of medium quality was obtained. From this, a DSM of 9216x4430 was created, with a spatial resolution of 1.05 cm/pixel and finally, an orthomosaic of 36864x17720 with a spatial resolution of 2.62 mm/pixel (Figure 4).

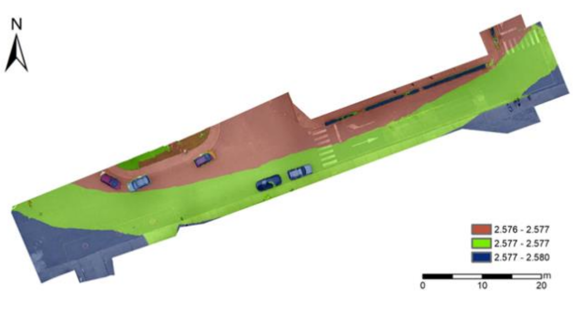

Figure 4. DSM and orthophoto.

The DSM obtained at 10-meter flights provides essential information on the topography of the terrain, particularly elevations and slopes as shown in Figure 5.

In order to analyze the IRI, it was necessary to rely on the ProVal software, which from the profile shown in Figure 6 and the parameters mentioned in Table 3, generates a roughness profile as follows.

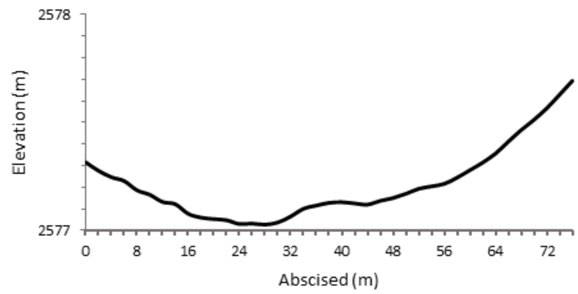

Figure 5. Longitudinal profile of the study section.

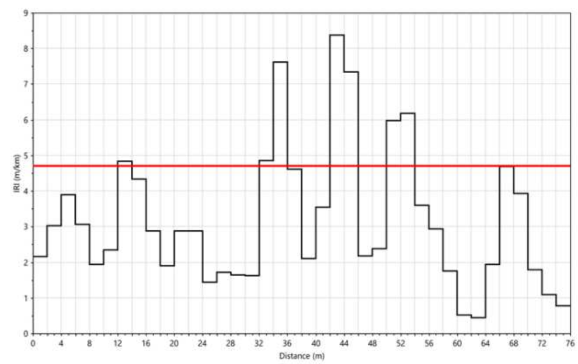

Figure 6. Variation of IRI as a function of sampling range.

4 ANALYSIS

From the information obtained, it is possible to affirm that the flight and processing parameters selected are suitable for this type of research, since their implementation allows obtaining products with acceptable characteristics in terms of resolution and accuracy for the extraction of road infrastructure information.

However, it is necessary to analyze flight parameters such as frontal and lateral overlaps because, although values of 75 and 65% respectively were considered, following the recommendations of (Romero-Chambi et al. 2020), increasing their value represents obtaining a greater number of homologous points and a better correlation between them. Thus, in the case of obstacles such as pedestrians, vehicles, or others, it is possible to make modifications to the point cloud from the various images captured of the region thanks to the overlays considered, obtaining then a partially or completely clear road (Cruz & Gutierrez 2019).

On the other hand, despite reaching a low error for the flight at 10 meters, it is possible to obtain additional information useful for localization and scaling by using GCPs. These improve accuracy by serving as tie points that increase the relative accuracy levels and the absolute position of the model (Atencio et al. 2022).

The UAV flight height is based on the camera characteristics and the predefined pixel representation on the ground, or ground sampling distance (GSD) (Prosser-Contreras et al. 2020), where some authors as Cruz & Gutierrez 2019, recommend capturing information by relating variables such as GSD between ranges of 0,30 to 0,35 cm/pixel.

5 CONCLUSIONS

This method has several advantages over the traditional method, since it allows the capture of information without interrupting the flow of vehicles, reduces the risk of accidents to personnel and acquires information quickly and continuously. Once the data is obtained, it can be processed at convenience and different data can be obtained with a single survey or flight in different areas, even those that are difficult to access.

Thus, for the case study, this method allows to analyze the profiles and the behavior of the IRI in the traffic width, discriminating sections or covering the entire road.

Although the final products are supported by the accuracy values achieved, which in turn are compared with the data present in the scientific literature, these can be validated through comparison with the results of field tests. Thus, it is possible to perform the survey of lesions through methodologies such as PCI, IRI estimation with profilometer, among others, since the information acquired by the UAV can be analyzed as many times as necessary without the need to perform another flight.

As a reference in future research, the objective should be to search for optimal combinations of variables and GCPs distribution, so as to ensure acceptable results and products in different flight and study situations. Similarly, another source of research corresponds to the implementation of artificial intelligence techniques for the extraction and processing of information from dense point clouds.

4 ACKNOWLEDGEMENTS

We want to express our most sincere gratitude to the GIISAG Research Group and the SIMODIG Seedbed for their invaluable collaboration and dedication during the research process.

Likewise, we extend our recognition to all the engineers and students who actively participated in this project, whose contributions were fundamental to its development. Their commitment and enthusiasm were essential to the generation of documents that supported this work.

Additionally, we would like to thank UPTC and the School of Civil Engineering for their continued support and for providing us with the space and resources necessary to successfully carry out this research.

5 REFERENCES

1. Agisoft LLC (Edition 2.0.4) [Software] Available in: https://www.agisoft.com/.
2. Atencio E., Plaza-Muñoz F., Muñoz-La Rivera F. and Lozano-Galant J. A. 2022. Calibration of UAV flight parameters for pavement pothole detection using orthogonal arrays. *Autom. Constr.* 143. doi: 10.1016/j.autcon.2022.104545.
3. Badilla G. 2011. Aspectos y consideraciones importantes en el cálculo del Índice de Regularidad Internacional (IRI). *Rev. Ing.* 20(1). doi: 10.15517/ring.v20i1-2.7271.
4. Chun P. J., Yamane T. and Tsuzuki Y. 2021. Automatic detection of cracks in asphalt pavement using deep learning to overcome weaknesses in images and gis visualization. *Appl. Sci.* 11(3), 1–15. doi: 10.3390/app11030892.
5. Cruz J. O. y Gutierrez J. W. 2019. Evaluación superficial de vías urbanas empleando vehículo aéreo no tripulado (VANT). *Métodos y Mater.* 8, 23–32. doi: 10.15517/mym.v8i1.34113.
6. De Solminihac H., Eechhaveguren T. y Chamorro A. 2019. Gestión de infraestructura vial. 659–689. Santiago, Chile. doi: 10.2307/j.ctvkjb4dw.23.
7. Esri (Edition 10.8) [Software] Available in: https://www.esri.com/es-es/arcgis/products/arcgis-desktop/resources.
8. Ferrer-González E., Agüera-Vega F., Carvajal-Ramírez F. and Martínez-Carricondo P. 2020. UAV photogrammetry accuracy assessment for corridor mapping based on the number and distribution of ground control points. *Remote Sens.* 12(15). doi: 10.3390/RS12152447.
9. Gopalakrishnan K. 2018. Deep learning in data-driven pavement image analysis and automated distress detection: A review. *Data*. 3(3). doi: 10.3390/data3030028.
10. Gui R., Xu X., Zhamg D., Lin H., Pu F., He L. and Cao M. 2018. A component decomposition model for 3D laser scanning pavement data based on high-pass filtering and sparse analysis. *Sensors*. 18(7), 2294. doi: 10.3390/s18072294.
11. Herra L. D. 2018. Conceptualización del procesamiento digital de imágenes para la evaluación de superficies de pavimento en Costa Rica. *Infraestructura. Vial* 20 (35), 20–26. doi: 10.15517/iv.v20i35.34831.
12. Hoang N. D. 2018. An artificial intelligence method for asphalt pavement pothole detection using least squares support vector machine and neural network with steerable filter-based feature extraction. *Adv. Civ. Eng.* 1, 1–12. doi: 10.1155/2018/7419058.
13. Kashiyama T., Sekimoto Y., Seto T. and Lwin K. K. 2020. Analyzing road coverage of public vehicles according to number and time period for installation of road inspection systems. *Int. J. Geo-Information*, 9 (161), 1–14. doi: 10.3390/ijgi9030161.
14. Ministerio de Transporte. 2016. *Volumen 1: Aspectos Informativos*. Bogotá D.C.
15. Ministerio de Transporte. 2006. *Manual para la inspección visual de pavimentos flexibles*, Bogotá D.C.
16. Pan Y., Zhang X., Cervone G. and Yang L. 2018. Detection of asphalt pavement potholes and cracks based on the Unmanned Aerial Vehicle multispectral imagery. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* 11 (10), 3701–3712. doi: 10.1109/JSTARS.2018.2865528.
17. Prosser-Contreras M., Atencio E., La Rivera F. M. and Herrera R. F. 2020. Use of Unmanned Aerial Vehicles (UAVs) and photogrammetry to obtain the International Roughness Index (IRI) on roads. *Appl. Sci.* 10(24), 1–22. doi: 10.3390/app10248788.
18. Ragnoli A., De Blasiis M. R. and Di Benedetto A. 2018. Pavement distress detection methods: A review. *Infrastructures*. 3(4), 1–19. doi: 10.3390/infrastructures3040058.
19. Romero-Chambi E., Villarroel-Quezada S., Atencio E. and La Rivera F. M. 2020. Analysis of optimal flight parameters of unmanned aerial vehicles (UAVs) for detecting potholes in pavements. *Appl. Sci*. 10(12), 1–33. doi: 10.3390/APP10124157.
20. Sayers M. 1995. On the calculation of International Roughness Index from longitudinal road profile. *Transp. Res. Rec.* 1501, 1–12.
21. Strategic Highway Research Program, Manual for profile measurement: Operational field guidelines. 1994. Washington.
22. Tan Y. and Li Y. 2019. UAV photogrammetry-based 3D road distress detection. *Int. J. Geo- Information*. 8(409), 1–24. doi: 10.3390/ijgi8090409.
23. U.S. Department of Transportation Federal Highway Administration (edition 3.61.50) [Software] Available in: https://www.roadprofile.com/software-overview/older-versions/.
24. Wang Y. and Ye T. 2022. Applications of artificial intelligence enhanced drones in distress pavement, pothole detection, and healthcare monitoring with service delivery. *Journal Engineering*. 2022, 1–16. doi: 10.1155/2022/7733196.
25. Yousaf M. H., Azhar K., Murtaza F. and Hussain F. 2018. Visual analysis of asphalt pavement for detection and localization of potholes. *Adv. Eng. Informatics*. 38, 527–537. doi: 10.1016/j.aei.2018.09.002.

26. Zhang Y., Chen B., Wang J., Li J. and Sun X. 2020. APlCnet: Automatic pixel-level crack detection network based on instance segmentation. *IEEE Access.* 8, 199159–199170. doi: 10.1109/ACCESS.2020.3033661.