Research Journal of Agricultural Science, 58 (1), 2026; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2026.1.29

ASSESSMENT OF VERTICAL SYSTEMATIC ERROR IN UAV-PPK PHOTOGRAMMETRY WITH AND WITHOUT GROUND CONTROL POINTS IN MOUNTAINOUS TERRAIN

Bogdan POPOVICI[1], (ORCID: 0009-0002-0232-2794); Mihai Valentin HERBEI[2,3], (ORCID: 0000-0002-3884-3658); Mihai AVĂDANEI[2], Florin SALA[3], (ORCID: 0000-0002-8876-590X), Olivier BOURIAUD[4]

[1]Ștefan cel Mare University of Suceava, 13 Universitatea Street, Suceava, Romania

[2]University of Petroșani, 20 University Street, Petroşani, Romania

[3]University of Life Sciences 'King Mihai I' from Timisoara, 119 Calea Aradului, Timisoara, Romania

Corresponding author: florin_sala@usvt.ro

Abstract. *UAV photogrammetry combined with post-processed kinematic positioning (PPK) is a widely used solution for obtaining high-resolution topographic models. However, the absolute vertical accuracy of photogrammetric models based solely on PPK, in the absence of ground control points (GCPs), remains poorly understood, particularly in complex mountainous terrain. This study investigates the magnitude and consistency of the systematic vertical bias in UAV-PPK photogrammetry by comparing two processing scenarios applied to the same dataset: (i) with GCPs and (ii) without GCPs. The analysis was conducted on three representative surface types — paved road, grassland and forest — using independent GNSS ground control points. The results show that the GCP-based solution achieves high vertical accuracy, with RMSE values ranging from 0.022 m to 0.069 m. In contrast, processing without GCPs reveals a negative systematic vertical bias of approximately −2.0 m, which is consistent across all surface types, with low internal dispersion (±0.02–0.03 m). This behavior indicates that the error is predominantly systematic and manifests as a uniform vertical shift affecting the entire model. The observed bias exhibits similar values regardless of surface type and elevation variation, suggesting that the error is not driven by local terrain characteristics but is related to the absolute positioning of the photogrammetric model. The results highlight the crucial role of external constraints in the bundle adjustment process (the process of adjusting the photogrammetric image block) and underscore the importance of vertical reference consistency in PPK-based georeferencing. From an application perspective, the study shows that the exclusive use of PPK georeferencing, in the absence of GCPs or vertical reference verification, can lead to significant errors in absolute altitudes. The introduction of even a minimal number of GCPs enables the effective elimination of this systematic offset and ensures reliable vertical accuracy.*

Keywords: *UAV photogrammetry, PPK, ground control points, systematic vertical bias, altimetric accuracy, georeferencing, bundle adjustment, vertical reference.*

INTRODUCTION

UAV photogrammetry has become an effective method for producing digital surface models (DSMs), orthophotomaps and 3D point clouds, offering a low-cost alternative to traditional aerial photogrammetry (NEX AND REMONDINO, 2014). The integration of precision GNSS receivers into UAV systems – using RTK and PPK methods – enables the direct georeferencing of images, thereby reducing reliance on ground control points (GCPs). Survey-grade receivers substantially improve accuracy compared to lower-quality GPS solutions (HUGENHOLTZ ET AL., 2016), but systematic elevation error remains a recognized issue in the absence of GCPs (ŠTRONER ET AL., 2021; MARTÍNEZ-CARRICONDO ET AL., 2023). Elevation errors are primarily associated with the absence of external constraints in bundle block adjustment (BBA) and can reach several decimetres, being linearly dependent on focal length deviation (ŠTRONER ET AL., 2021). The vertical RMSE without GCPs can reach 0.087 m (~5×GSD), and is significantly reduced by adding a single GCP (LIU ET AL., 2022; CHO AND LEE, 2023). The number and distribution of GCPs significantly influence the final planimetric and altimetric accuracy (SANZ-ABLANEDO ET AL., 2018; MARTÍNEZ-CARRICONDO ET AL., 2018; AGÜERA-VEGA ET AL., 2017; FERRER-GONZÁLEZ ET AL., 2020), with vertical accuracy being systematically lower than horizontal accuracy (DELIRY AND AVDAN, 2021; ELKHRACHY, 2021).

In mountainous and forested terrain, the mean errors without GCPs exceed the values obtained with well-distributed GCPs by up to 0.12 m (NESBIT ET AL., 2022; TOMAŠTÍK ET AL., 2019). Alternative strategies – the simultaneous use of multiple GNSS base stations – have enabled altimetric improvements of 14–35% without GCPs (MARTÍNEZ-CARRICONDO ET AL., 2023). The UAV–PPK–SfM workflow has proven to be robust for monitoring surface changes in hard-to-reach areas (ZHANG ET AL., 2019), and a comparison of bundle block adjustments (BBA) with and without GCPs highlights the limitations of direct georeferencing in complex terrain (ŽABOTA AND KOBAL, 2021). Flight configuration and acquisition pattern influence the accuracy of the photogrammetric block (GERKE AND PRZYBILLA, 2016), and the addition of precision GPS constraints significantly improves the external accuracy of UAV products (RAUHALA, 2023). However, the explicit quantification of systematic vertical bias under real-world mountain terrain conditions, across different surface types, remains insufficiently studied.

This study quantitatively assesses this bias by comparing UAV-PPK processing with and without GCPs on tarmac, grassland and forest in the Dobârlău mountain area, Covasna County, Romania, and provides insights into: (1) the quantification of a large systematic bias (~2 m) in the absence of GCPs; (2) its consistency across different surface types; (3) practical implications for surveying and engineering applications.

MATERIALS AND METHODS

Study area

The study area is located in Dobârlău commune, Covasna county, Romania (45°44'N, 25°52'E), in the Pulkovo 1942(58) / Stereo70 coordinate system. The geographical location of the area, at both national and county level, as well as the boundaries of the study area, are shown in Figure 1. The total area analyzed is 52.3 ha and exhibits a significant variation in altitude, with values ranging from approximately 536 m (in the area of the tarmac road) to 667 m (in the upper forest area), corresponding to a difference in elevation of around 130 m. The vertical accuracy analysis was carried out at specific points, around three reference points located on surfaces with different textures (tarmac road, pasture and forest). The terrain is characterized by a pronounced slope and comprises four main land cover types: a paved county road, pasture, pine forest and beech forest. For the photogrammetric analysis, three representative land cover types were selected – tarmac road, pasture and forest – each associated with an independent GNSS control point. The selection of these surfaces enables the assessment of the influence of surface texture and structure on vertical accuracy under various conditions. The flight was conducted during the dormant vegetation period (25 March 2025), thereby minimizing the impact of vegetation on the photogrammetric reconstruction and ensuring comparable conditions across the different surfaces.

Research Journal of Agricultural Science, 58 (1), 2026; ISSN: 2668-926X;
http://doi.org/10.59463/RJAS.2026.1.29

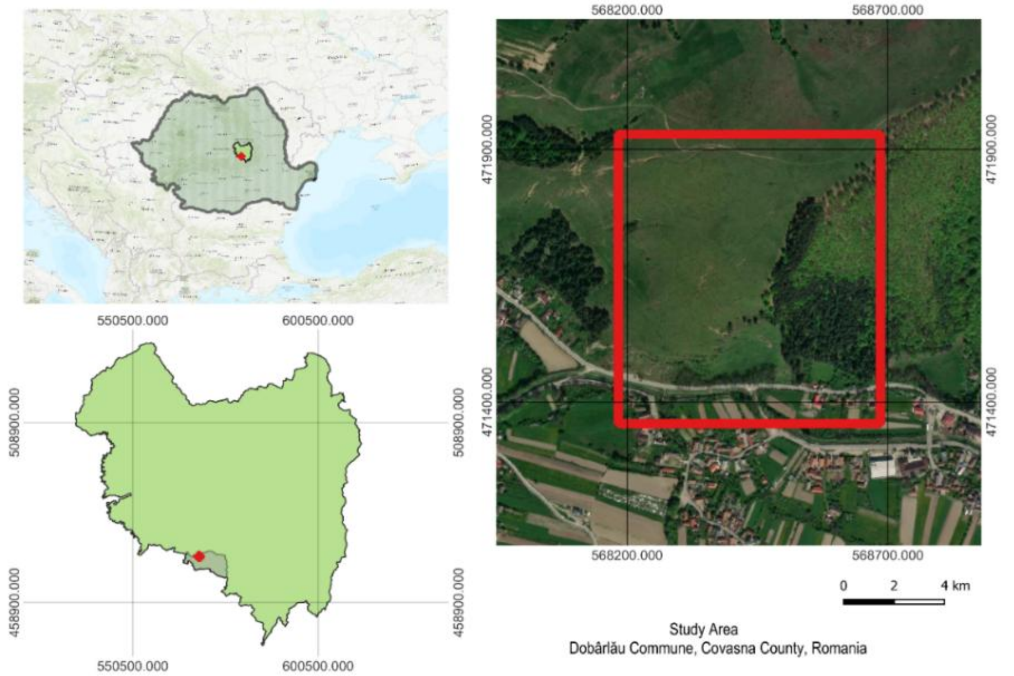

Figure 1. Location of the study area in Dobârlău commune, Covasna county, Romania, in the Stereo70 coordinate system. The red outline marks the area of the 52.3 hectares covered photogrammetrically. Altitudes range from ~536 m (paved road area, south) to ~667 m (forest area, north).

Equipment and flight parameters

Data acquisition was carried out using the Wingtra ONE UAV platform (fixed-wing VTOL — vertical take-off and landing type), equipped with a Sony RX1RII camera (42-megapixel full-frame sensor, 35 mm prime lens). This configuration ensures a low GSD and a favourable image geometry for high-precision photogrammetric reconstruction. The main parameters of the survey are presented in Table 1.

Table 1

Parameters of the UAV photogrammetric campaign, Dobârlău, 25 March 2025

Parameter	Value
UAV platform	Wingtra ONE (fixed-wing VTOL)
Camera	Sony RX1RII (full-frame sensor, 42 MP, 35 mm prime lens)
Flight date	25 March 2025, 09:35 UTC
Flight altitude above ground level	85 m above ground
Area covered	52.3 ha
Number of images	1,352 images (100% calibrated)
Average GSD	1.75 cm/pixel

Forward/side overlap.	~80% / ~70% (estimated)
PPK processing	Yes — WingtraHub v2.12.1
PPK Fix	100%
Average PPK accuracy	±0.02 m horizontal / ±0.03 m vertical
Base GNSS receiver	Trimble R12i (TRMR12I NONE), RINEX 3.04, 45 satellites
Base station coordinates	45°44'10.27"N, 25°52'28.10"E, H = 578.70 m
Photogrammetry software	Pix4Dmapper v4.10.0
Output coordinate system	Pulkovo 1942(58) / Stereo 70
Number of GCPs (Variant A)	7 3D GCPs, RMS error = 0.02 m
Densified point cloud (Variant A)	~261 million 3D points, average density 593 points/m^2
Densified point cloud (Variant B)	~260 million 3D points, average density 446 points/m^2

The georeferencing of the images was performed using the PPK technique, utilising RINEX files (version 3.04) from a Trimble R12i GNSS base station (type TRMR12I NONE), located at the coordinates 45°44'10.27"N, 25°52'28.10"E, H = 578.70 m. PPK processing was carried out in WingtraHub v2.12.1 software, achieving a 100% fix rate for all 1,352 images and an estimated mean accuracy of ±0.02 m horizontally and ±0.03 m vertically.

Photogrammetric processing

Image processing was carried out in Pix4Dmapper v4.10.0 software, using the same set of PPK georeferenced images for two distinct processing scenarios:

- **Variant A — With ground control points (GCPs):** Standard photogrammetric processing using 7 3D GCPs distributed across the study area. The GCPs were measured using a Trimble R8S GNSS receiver in RTK mode, with an XY/Z accuracy of ±0.020 m. Processing RMS error: 0.02 m. Number of densified 3D points: ~261 million, average density 593 points/m^2.
- The GCPs were distributed uniformly across the study area, covering the entire elevation range and ensuring that the photogrammetric model was correctly aligned with the ground reference values.
- **Variant B — No ground control points (PPK-only):** Processing based solely on the PPK positions of the cameras, with no GCPs in the bundle adjustment block. Number of densified 3D points: ~260 million, average density 446 pts/m^2. The difference in density compared to Variant A (−25%) suggests a degradation in the geometric consistency of the model in the absence of external constraints. All other processing settings (image scale: Full/0.5; densification: multiscale 1/2, optimal density; DSM resolution: 1×GSD = 1.75 cm/pixel) were kept identical in both scenarios to ensure the comparability of the results.

Verification points and analysis methodology

Vertical accuracy validation was performed using three independent survey markers, measured with the Trimble R8S GNSS receiver in RTK mode. The three points (Table 2) were strategically located on three different types of surface – a tarmacked road, grassland and forest – and cover the entire elevation range of the study area (536–667 m). The same three markers were used in both processing scenarios, renamed for each variant: 1500/2500/3500 (with GCP) and 1000/2000/3000 (without GCP), with a direct correspondence between them.

Table 2

Coordinates of the ground control points (Trimble R8S GNSS, Stereo70 system)

Point	X (m)	Y (m)	Z (m)	Surface type	Instrument
1,500 / 1,000	568,491.899	471,423.548	536,040	Asphalt road	Trimble R8S
2500 / 2000	568,503,248	471,475.879	557,863	Pasture	Trimble R8S
3,500 / 3,000	568,590.966	471,758.868	666,940	Forest	Trimble R8S

For each verification point and each processing variant, elevation values were extracted from the densified point cloud by selecting all points located within a maximum radius of 0.5 m from the X, Y coordinates of the benchmark (9–16 points per benchmark, depending on the density of the local cloud). Vertical differences were calculated as ΔZ = Z_model − Z_GNSS, and on the basis of these differences, the following were determined: bias (mean ΔZ) and RMSE (root-mean-square error of ΔZ), which are standard statistical indicators used to assess the accuracy of photogrammetric products.

RESULTS AND DISCUSSION

Accuracy of processing with GCPs

The results obtained in Variant A (with GCPs) demonstrate high vertical accuracy for all three surface types analyzed. The vertical RMSE values range from 0.022 m (grassland) to 0.069 m (paved road), confirming the performance of the UAV-PPK system when appropriate external constraints are used. These values fall within the range of 0.020–0.090 m reported in the international literature for processing with GCPs in similar configurations (ŽABOTA AND KOBAL, 2021; RAUHALA, 2023). The distributions of the ΔZ errors for the three surface types are shown in Figures 2, 3 and 4, and a comparison of the distributions for the scenarios with and without GCPs is illustrated in Figures 5 and 6. The summary values for bias and RMSE are presented in Table 3. Point-by-point analysis of the distributions shows that the errors are predominantly random, with low dispersion and no systematic trend, confirming that georeferencing with GCPs eliminates the systematic component of the error. The best accuracy was achieved on the pasture surface (Figure 3) (bias = −0.009 m; RMSE = 0.022 m), which can be explained by the relatively uniform texture of the horizontal surface and the favorable conditions for photogrammetric reconstruction in the absence of tall vegetation.

On the tarmac road (Figure 2), the positive bias of +0.069 m and the RMSE of 0.069 m indicate a slight systematic overestimation of the model compared to the actual area. This trend can be attributed to the uniform texture and high reflectivity of the asphalt, which affect the automatic image correlation and reduce the density of tie points on this surface. On the forest area (Figure 4), for the variant with GCPs, the ΔZ values range from −0.097 m to −0.043 m, with an RMSE of 0.066 m. The slightly higher dispersion compared to the grassland is explained by the irregularity of the tree canopy and the partial penetration of the point cloud through the canopy, even under conditions of vegetative dormancy.

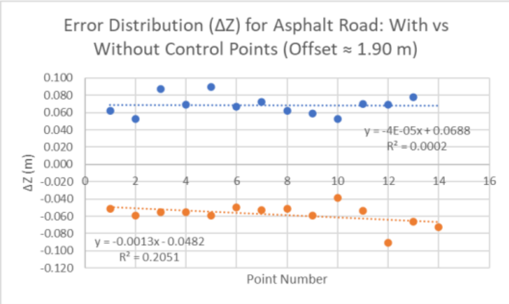

Figure 2.
Distribution of vertical errors ΔZ for the tarmac road (Point 1500/1000, Z_bornă = 536.040 m): comparison between Variant A (With GCPs, blue series) and Variant B (Without GCPs, orange series). It can be observed that the values for the With GCP variant cluster around zero (+0.053 m ... +0.090 m), whereas the values for the No GCP variant show a systematic shift of approximately −1.95 m from the reference value (total offset ≈ 1.90 m). The dotted lines represent the linear trends of each series.

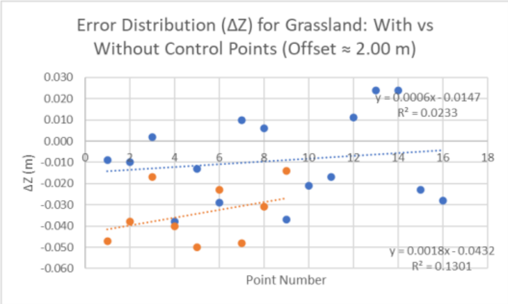

Figure 3.
Distribution of vertical errors ΔZ for the pasture (Point 2500/2000, Z_benchmark = 557.863 m): comparison between Variant A (With GCP) and Variant B (Without GCP). The With GCP values are centred around zero (−0.038 m ... +0.024 m), confirming the high level of accuracy. The values without GCP show a consistent negative systematic bias of approximately −2.03 m (total offset ≈ 2.00 m), identical in value to that observed on the tarmac road.

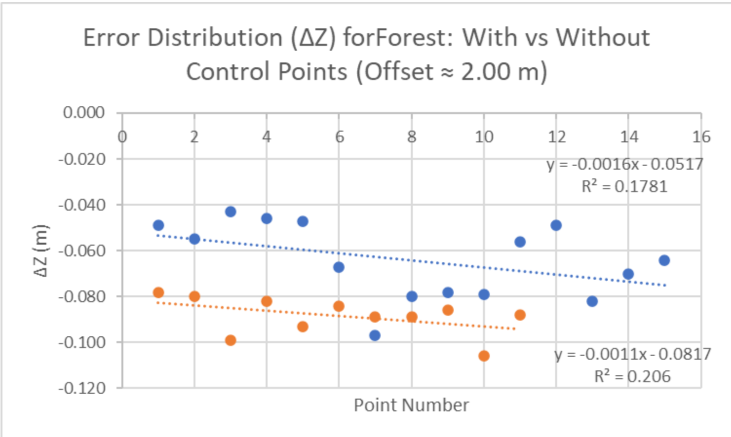

Figure 4.
Distribution of vertical errors ΔZ for the forest (Point 3500/3000, Z_benchmark = 666.940 m): comparison between Variant A (with GCP) and Variant B (without GCP). Although the forest is located at an altitude 130 m higher than the tarmac road, the bias in the No GCP scenario remains virtually unchanged (≈ −2.09 m, total offset ≈ 2.00 m), demonstrating that the value of the systematic error is independent of altitude and surface type.

Systematic vertical bias in processing without GCPs

The main finding of the study is the identification of a large negative systematic vertical bias in Variant B (without GCPs), which is consistent across all three surface types analysed.

The full values are presented in Table 3, and the distributions of the ΔZ errors for the scenarios with and without GCPs are illustrated comparatively in Figures 5 and 6.

Table 3

Comparative results of vertical accuracy (bias and RMSE) With GCPs (blue) vs. Without GCPs (red)

Method / Terrain	Bias (m)	RMSE (m)	ΔZ min (m)	ΔZ max (m)
With GCP — Tarmacked road	+0.069	0.069	+0.053	+0.090
With GCP — Grassland	−0.009	0.022	−0.038	+0.024
With GCP — Forest	+0.064	0.066	−0.097	−0.043
Without GCP — Tarmacked road	−1.958	1.958	−1.991	−1.939
Without GCP — Grassland	−2.034	2.034	−2.050	−2.014
Without GCP — Forest	−2.089	2.089	−2.106	−2.078

On the paved road, the bias without GCPs reached −1.958 m (RMSE = 1.958 m), on the grassland −2.034 m (RMSE = 2.034 m), and in the forest −2.089 m (RMSE = 2.089 m). The individual ΔZ values exhibit low dispersion within each surface type (±0.02–0.03 m from the mean), confirming that the error is purely systematic rather than random. This means that the entire photogrammetric model is vertically offset by ~2 m from reality, uniformly across the entire surface.

Figures 5 and 6 compare the statistical distribution of bias and RMSE for all six surface–method combinations. Figure 5 shows that, in the With GCP scenario, the bias values are small and of varying sign (between −0.009 m and +0.069 m), indicating the absence of a dominant systematic component.

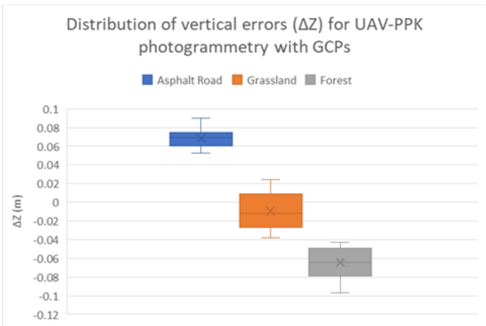

Figure 5.
Comparison of bias and vertical RMSE (ΔZ) in the With GCP scenario for the three surface types. The bias (blue) and RMSE (orange) values are in the centimetre range across all surfaces, confirming that georeferencing with 7 GCPs effectively eliminates the systematic component of the error. Grassland achieves the best performance (RMSE = 0.022 m), followed by forest (0.066 m) and tarmac road (0.069 m).

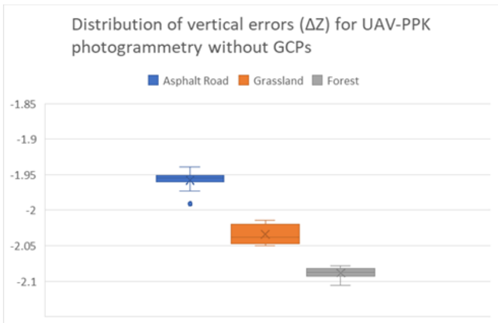

Figure 6.
Comparison of bias and vertical RMSE (ΔZ) in the No GCP scenario for the three surface types. The bias (negative, orange) and RMSE values are in the order of metres across all surfaces (~2 m), demonstrating the presence of a systematic bias of uniform magnitude, independent of the surface type. The close similarity between the bias and RMSE values confirms that the error is almost entirely systematic, not random.

The differences between the surface types are small, with grassland having the lowest RMSE values, followed by forest and tarmac. The RMSE values are virtually identical to the bias values, confirming that the error is predominantly systematic and consistent across all surface types.

Comparative analysis by surface type

The observed bias values, which are similar across all surface types, indicate that the error is not influenced by the surface type or the data acquisition process, but is related to the absolute positioning of the photogrammetric model.

In the absence of ground control points, the model is georeferenced solely on the basis of the PPK solution, which may result in a global vertical offset. The fact that the bias remains constant across all analysed surfaces and over the entire altimetric range suggests that there is a systematic difference between the vertical references used in processing and those used for validation.

DISCUSSION

The results obtained highlight the existence of a high-magnitude systematic vertical bias in the processing scenario without ground control points (GCPs), with values of approximately −2.0 m, which are consistent across all three surface types analysed. This uniformity, observed on the paved road (−1.958 m), the grassland (−2.034 m) and the forest (−2.089 m), despite an elevation variation of approximately 130 m between the ground control points, indicates that the error is of a global nature, independent of local terrain conditions. The distribution of the ΔZ values and their low dispersion around the mean value (±0.02–0.03 m) confirm the predominantly systematic nature of the error. The photogrammetric model obtained without GCPs exhibits a constant vertical offset from the reference values used for validation, although the internal structure of the model is correct. The difference between the two scenarios is determined by the absolute positioning of the model. In the scenario with GCPs, the model is correctly anchored to the reference elevations on the ground, which enables the elimination of global deviations. In their absence, the positioning is based solely on the PPK solution, which may result in a systematic difference in the vertical positioning of the model.

The observed bias value (~2 m), which is significantly higher than values commonly reported in the literature, suggests that the error is related to the method of absolute positioning of the model. One possible explanation is the existence of a systematic difference between the vertical references used in data processing and those used for validation. However, this hypothesis requires further verification and cannot be directly confirmed based on the available data. Such differences may give rise to a constant vertical displacement, which is consistent with the results obtained. The uniform nature of the error across all the analysed areas confirms that it is not influenced by terrain texture or local conditions, but is related to the absolute positioning method of the model. These results are consistent with studies highlighting the limitations of direct georeferencing in the absence of GCPs and the need for external constraints to control absolute accuracy.

From a practical perspective, the results show that using PPK georeferencing alone, without integrating GCPs or verifying the vertical reference, can lead to significant errors in absolute altitudes, even if the model is relatively correct.

CONCLUSIONS

This study assessed the vertical accuracy of UAV-PPK photogrammetry by comparing two processing scenarios applied to the same dataset: with ground control points (GCPs) and without GCPs, in the context of mountainous terrain with significant elevation variation.

The results obtained lead to the following main conclusions:

- **Processing with GCPs** delivers high vertical accuracy, with RMSE values ranging from 0.022 m to 0.069 m, confirming the effectiveness of using external constraints in obtaining accurate and stable elevation models.
- **Processing without GCPs** generates a negative systematic vertical bias, with values ranging from −1.958 m to −2.089 m. The small dispersion of the ΔZ values (±0.02–0.03 m) indicates that the error is predominantly of a systematic nature.
- **The bias values** are consistent across all surface types and over the entire altimetric range analysed, indicating the global nature of the error and its independence from local conditions.
- **The fundamental difference** between the two scenarios lies in the presence of external constraints in the bundle adjustment. In the absence of GCPs, the model may exhibit an overall vertical offset.
- **The results strongly suggest that the error** is associated with the absolute positioning process, most likely due to differences between the vertical reference systems used in processing and those used for validation.

From an application perspective, the study shows that using PPK georeferencing alone, without integrating GCPs or verifying the vertical reference, can lead to significant errors in absolute altitudes. Consequently, the use of a minimum number of ground control points or the careful verification of the vertical reference are essential conditions for ensuring absolute accuracy in surveying and engineering applications. The limitations of the study are the small number of verification points and the analysis of a single dataset. Future research could extend the analysis by using a larger number of points and by investigating other processing configurations.

BIBLIOGRAPHY

AGÜERA-VEGA, F., CARVAJAL-RAMÍREZ, F., & MARTÍNEZ-CARRICONDO, P. (2017). Assessment of photogrammetric mapping accuracy based on variation in the number of ground control points using unmanned aerial vehicles. *Measurement*, *98*, 221–227.

CHO, J. M., & LEE, B. K. (2023). GCP and PPK utilisation plan to deal with RTK signal interruption in RTK-UAV photogrammetry. *Drones*, *7*(4), 265.

DELIRY, S. I., & AVDAN, U. (2021). Accuracy of unmanned aerial systems photogrammetry and structure from motion in surveying and mapping: a review. *Journal of the Indian Society of Remote Sensing*, *49*(8), 1997–2017.

ELKHRACHY, I. (2021). Accuracy assessment of low-cost unmanned aerial vehicle (UAV) photogrammetry. *Alexandria Engineering Journal*, *60*(6), 5579–5590.

FERRER-GONZÁLEZ, E., AGÜERA-VEGA, F., CARVAJAL-RAMÍREZ, F., & MARTÍNEZ-CARRICONDO, P. (2020). UAV photogrammetry accuracy assessment for corridor mapping based on the number and distribution of ground control points. *Remote Sensing*, *12*(15), 2447.

GERKE, M., & PRZYBILLA, H. J. (2016). Accuracy analysis of photogrammetric UAV image blocks: Influence of onboard RTK-GNSS and cross-flight patterns. *Photogrammetrie, Fernerkundung, Geoinformation*, *2016*(1), 17–30.

HUGENHOLTZ, C., BROWN, O., WALKER, J., BARCHYN, T., NESBIT, P., KUCHARCZYK, M., & MYSHAK, S. (2016). Spatial accuracy of UAV-derived orthoimagery and topography: Comparing photogrammetric models processed with direct georeferencing and ground control points. *Geomatica*, *70*(1), 21–30.

LIU, X., LIAN, X., YANG, W., WANG, F., HAN, Y., & ZHANG, Y. (2022). Accuracy assessment of a UAV direct georeferencing method and the impact of ground control point configuration. *Drones*, *6*(2), 30.

MARTÍNEZ-CARRICONDO, P., AGÜERA-VEGA, F., & CARVAJAL-RAMÍREZ, F. (2023). Accuracy assessment of RTK/PPK UAV photogrammetry projects using differential corrections from multiple GNSS fixed base stations. *Geocarto International*, *38*(1), 2197507.

MARTÍNEZ-CARRICONDO, P., AGÜERA-VEGA, F., CARVAJAL-RAMÍREZ, F., MESAS-CARRASCOSA, F. J., GARCÍA-FERRER, A., & PÉREZ-PORRAS, F. J. (2018). Assessment of UAV-photogrammetric mapping accuracy based on variation in ground control points. *International Journal of Applied Earth Observation and Geoinformation*, *72*, 1–10.

NESBIT, P. R., HUBBARD, S. M., & HUGENHOLTZ, C. H. (2022). Direct georeferencing UAV-SfM in high-relief topography: Accuracy assessment and alternative ground control strategies along steep, inaccessible rock slopes. *Remote Sensing*, *14*(3), 490.

NEX, F., & REMONDINO, F. (2014). UAVs for 3D mapping applications: A review. *Applied Geomatics*, *6*(1), 1–15.

RAUHALA, A. (FEBRUARY 2023). Accuracy assessment of UAS photogrammetry with GCP- and PPK-assisted georeferencing. In *International conference on FinDrones* (pp. 57–73). Cham: Springer Nature Switzerland.

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 the ground control points used. *Remote Sensing*, *10*(10), 1606.

ŠTRONER, M., URBAN, R., SEIDL, J., REINDL, T., & BROUČEK, J. (2021). Photogrammetry using UAV-mounted GNSS RTK: Georeferencing strategies without GCPs. *Remote Sensing*, *13*(7), 1336.

TOMAŠTÍK, J., MOKROŠ, M., SUROVÝ, P., GRZNÁROVÁ, A., & MERGANIČ, J. (2019). UAV RTK/PPK method—An optimal solution for mapping inaccessible forested areas? *Remote Sensing*, *11*(6), 721.

ZHANG, H., ALDANA-JAGUE, E., CLAPUYT, F., WILKEN, F., VANACKER, V., & VAN OOST, K. (2019). Evaluating the potential of post-processing kinematic (PPK) georeferencing for UAV-based structure-from-motion (SfM) photogrammetry and surface change detection. *Earth Surface Dynamics*, *7*(3), 807–827.

ŽABOTA, B., & KOBAL, M. (2021). Accuracy assessment of UAV-photogrammetric-derived products using PPK and GCPs in challenging terrains: In search of optimised rockfall mapping. *Remote Sensing*, *13*(19), 3812.