

# Evaluating UAV RTK Photogrammetry Mapping Accuracy in Urban Areas without Ground Control Points

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**Abstract** - Unmanned Aerial Vehicles (UAVs) equipped with Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) technology have gained prominence in geospatial applications, particularly in urban environments. This study focuses on assessing the mapping accuracy of UAV RTK photogrammetry in urban areas without the traditional use of Ground Control Points (GCPs). The exclusion of GCPs is motivated by the desire to streamline data acquisition processes and reduce the time and cost associated with fieldwork. The study employs a comprehensive evaluation framework to analyze the accuracy of UAV RTK photogrammetry outputs, considering factors such as point cloud density, positional accuracy, and 3D model precision. Data acquisition is carried out using a state-of-the-art UAV platform equipped with high-resolution cameras and RTK-enabled GNSS receivers. Preliminary results indicate promising mapping accuracy without the need for GCPs, demonstrating the potential efficiency of UAV RTK photogrammetry in urban contexts. However, challenges related to GNSS signal obstructions and urban canyon effects are also explored, highlighting the need for further refinement in data processing algorithms. The findings of this study contribute valuable insights into the feasibility and limitations of UAV RTK photogrammetry for urban mapping applications, paving the way for optimized workflows in the rapidly evolving field of geospatial technology. The results show that the horizontal accuracy is  $\pm 0.025\text{m}$  and vertical accuracy is  $\pm 0.035\text{m}$ .

**Keywords:** UAV, RTK, Photogrammetry, Accuracy, GCP, urban areas.

## I. INTRODUCTION

In the rapidly advancing landscape of geospatial technology, Unmanned Aerial Vehicles (UAVs) have emerged as instrumental platforms for acquiring high-resolution aerial imagery and generating three-dimensional (3D) models. The integration of Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) technology with UAVs has ushered in a new era of precision and efficiency, particularly in urban mapping applications. Traditional mapping methodologies often rely on the deployment of Ground Control Points (GCPs) to achieve accurate georeferencing, but the advent of

UAV RTK photogrammetry raises intriguing possibilities for circumventing the need for these ground markers.

Urban areas, characterized by complex architectures, dynamic landscapes, and rapid development, pose unique challenges to geospatial mapping. The demand for up-to-date, high-precision spatial information in these environments has spurred interest in optimizing UAV-based mapping approaches. The omission of GCPs from the mapping process not only promises to streamline data acquisition but also raises questions about the inherent accuracy and reliability of RTK-enabled UAV systems in the intricate urban context.

This paper embarks on a comprehensive exploration of UAV RTK photogrammetry mapping accuracy in urban areas without the reliance on traditional GCPs. The decision to forego GCPs is motivated by a dual objective: first, to assess the autonomous precision of RTK-enabled UAV systems, and second, to address the practical challenges associated with deploying ground markers in densely populated urban landscapes. As the demand for timely and accurate geospatial data intensifies, understanding the capabilities and limitations of UAV RTK photogrammetry without GCPs becomes imperative.

The study endeavors to contribute significantly to the evolving discourse surrounding UAV-based mapping methodologies, specifically in urban environments. By scrutinizing diverse scenarios and employing advanced evaluation metrics, ranging from point cloud density to positional accuracy, the study seeks to provide nuanced insights into the feasibility and reliability of UAV RTK photogrammetry in urban mapping without GCPs.

Furthermore, as technological advancements continue to reshape the geospatial landscape, the outcomes of this research aspire to inform practitioners, policymakers, and researchers about the potential implications and optimizations in UAV-based mapping workflows for urban areas. The intricate interplay between UAV RTK photogrammetry, urban mapping challenges, and the absence of GCPs encapsulates the core focus of this paper, presenting a multidimensional perspective on the evolving paradigm of high-precision geospatial data acquisition in urban environments.

## II. METHODS AND APPROACH

### 2.1 Study area

The present study was undertaken to compare and assess the accuracy of UAV pose estimation based on the data generated by a drone's onboard navigation system.

To determine the accuracy of this method, the UAV flight was carried out in the center of the city of Kukes, Albania near "Mother Teresa" and "Eksod" streets. The surface of the area that was surveyed is approximately 12 ha.



Figure 1: Aerial photography of the selected urban area

DJI Phantom 4 RTK drone was used to perform UAV Photogrammetry. This drone has a 1-inch image sensor, and it shoots 20 MP JPG photos. The DJI Phantom 4 RTK is a high-precision aerial survey drone that combines centimeter-level navigation and positioning with a high-performance imaging system to improve survey efficiency and accuracy, reducing operational difficulty and cost.

The RTK module is integrated directly into the DJI Phantom 4 RTK, providing real-time positioning data for improved absolute accuracy on image metadata.



Figure 2: DJI Phantom 4 RTK drone

The Phantom 4 RTK camera has an aerial-optimized  $f/2.8$  wide-angle lens with a 24 mm equivalent focal length. It features eight elements - two aspherical - arranged in seven groups that fit into a smaller, more compact frame. Using DJI Phantom 4 RTK drone, we received rtk data through the connection with the Albanian national positioning network

ALBCORS, and this data was compared with the coordinates determined with high accuracy of check points determined by GPS and Total Station instruments. The DJI Phantom 4 RTK (Real-Time Kinematic) is designed to receive data corrections to enhance the accuracy of its positioning information. RTK technology relies on a network of reference stations to provide corrections to the GPS signals received by the UAV, allowing for centimeter-level accuracy in positioning. RTK technology involves a two-step process: a base station transmits correction data to the UAV, and the UAV's receiver uses this correction data to enhance the accuracy of its position calculations.

The correction data received from the base station includes information about the errors in the satellite signals, such as ionospheric and tropospheric delays. The Phantom 4 RTK's GNSS receiver applies these corrections in real-time to improve the accuracy of its position calculations.

Some CORS networks, including ALBCORS, operate based on a network baseline approach where corrections are calculated using multiple reference stations. This information typically includes baseline distances and azimuths from your UAV to nearby reference stations. We established a data link between the Phantom 4 RTK and the ALBCORS network using cellular network. Once connected to the ALBCORS network and configured with the correct network baseline information, the Phantom 4 RTK received real-time corrections and these corrections helped us to improve the positioning accuracy of the UAV in real-time.

Its images are consistently detailed with low distortion and low dispersion, ensuring that photos are sharp and vivid. The coordinate system of the images is WGS 84 (EPSG:4326).

### 2.2 Check points marking

To determine the accuracy of this method, we marked 6 check points and measured them with GPS instruments (Sokkia GRX3) and Total Station (Leica TS03) to obtain coordinates with high accuracy.



Figure 3: Types of Check Points used in this experiment

The coordinates of these control points will be used for comparison with the coordinates of the same points obtained by UAV Photogrammetry after processing aerial images without using control points.

**Table 1: Coordinates of 6 check points measured with GPS and Total Station**

Point	N (m)	E (m)	H (m)
St1	4660241.753	534477.381	398.702
St2	4660158.262	534440.454	396.114
St3	4660273.897	534591.637	397.383
St4	4660194.683	534617.655	397.577
St5	4660108.135	534538.686	397.789
St6	4660171.465	534675.842	397.471

### 2.3 UAV RTK Photogrammetry

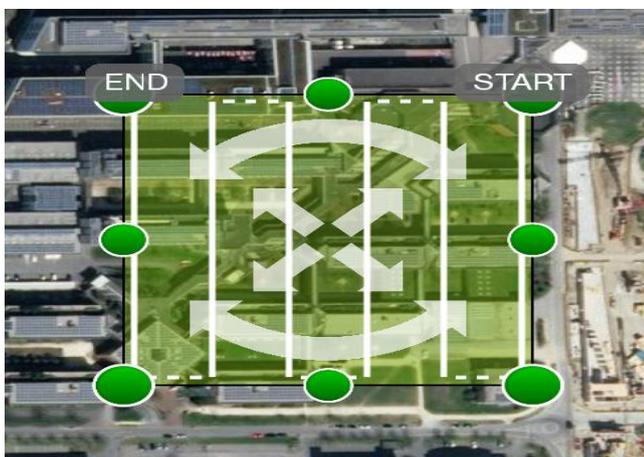
The first step was to plan the survey using optimal grid or transect patterns, considering the spatial distribution of features in the urban landscape. The flight planning was done using Pix4DCapture. In this case, grid mission was chosen to perform the flight using DJI Phantom 4 RTK.

#### Grid mission

Grid mission is used to plan and fly a nadir rectangle mission. It ensures that images are taken with the overlap required for optimal processing.

It is recommended to use grid mission in the following cases:

- Main interest in 2D map outputs (DSM, orthomosaic, etc.).
- Relatively flat surface (e.g. fields, earthworks).
- Large area.



**Figure 4: Grid mission in Pix4D Capture**

To perform area photography with the DJI Phantom 4 RTK, the following flight parameters are set:

height 60m, speed 4.2 m/s, picture size 3:2, sunny weather conditions, Cross coverage 85%, Longitudinal coverage 85%.

We used a height of 60 m to ensure a better overlap and higher-quality stereo pairs. At 60 meters, the ground coverage per pixel will be relatively moderate, providing a good balance between coverage area and resolution. Adequate overlap ensures accurate reconstruction of the terrain and features, contributing to the overall precision of the photogrammetric model. The speed of the UAV affects the overlap between consecutive images. A speed of 4.2 m/s was chosen to achieve the desired overlap while maintaining image quality. The speed of the UAV, along with the flying height, contributes to the Ground Sampling Distance (GSD), which is the distance between two consecutive pixel centers on the ground. The combination of speed and flying height influences the spatial resolution of the captured images. Adequate overlap, both cross and longitudinal, was essential for creating high-quality stereo pairs. An overlap of 85% ensures sufficient redundancy and coverage for accurate 3D reconstruction. A higher overlap percentage facilitates better feature matching between images. Tie points, which are common features identified in multiple images, play a crucial role in aligning and stitching the images together. A higher overlap improves the chances of capturing and matching tie points, enhancing the accuracy of the photogrammetric model.

The overlap percentage, along with flying height and speed, influences the Ground Sampling Distance (GSD), which is the distance between two consecutive pixel centers on the ground. An overlap of 85% contributes to a more uniform and accurate GSD across the entire survey area.

A balance between sufficient overlap and efficient data processing is crucial. An overlap of 85% provides enough redundancy for accurate reconstruction without overwhelming the data processing pipeline with excessive data.

### 2.4 Photogrammetric Data Processing

Aerial images exported from the drone were processed with Pix4DMapper software, which is one of the most used software for processing aerial images and extracting final products. This software automatically transforms the images taken by the drone and delivers high-precision products such as orthophotos and Digital Surface Model (DSM). The acquired aerial images were processed using PIX4D Mapper software to create the Point Cloud of the surveyed area. This software uses SfM (Structure from Motion) technique to reconstruct the scene based on many overlapping photos.



Figure 5: Workflow in Pix4DMapper

For the processing of aerial images in Pix4DMapper, initial processing was performed first. When starting initial processing, PIX4Dmapper first computes keypoints on the images. It uses these keypoints to find matches between the images. The software runs an Automatic Aerial Triangulation (AAT) and Bundle Block Adjustment (BBA) from these initial matches. If initial processing has already been done and is restarted, the software uses the existing keypoints and matches and starts the AAT and BBA.

For our case, the coordinate system for final products such as Point Cloud, 3d Mesh, DSM and Orthophoto was chosen UTM Zone 34N (epsg: 32634).

Then, in the Pix4DMapper software, the corresponding template was defined as 3D maps, which gives us the products mentioned above.

This process generated a digital elevation model (DEM) and the orthophoto of the area surveyed.

### 3D model generation

The second step of image processing in Pix4DMapper, after the initial processing, was the generation of the Point Cloud and 3d mesh. Point cloud is a discrete set of data points in space. Points can represent a 3D shape or object. Each point position has its own set of Cartesian coordinates (X, Y, Z). Point clouds are generally produced by 3D scanners or photogrammetry software, which measure many points on the outer surfaces of objects around them.

As a result of 3D scanning processes, point clouds are used for many purposes, including creating 3D computer-aided design (CAD) models for manufactured parts, for metrology and quality inspection, and for a variety of visualization, animation, rendering and mass customization applications. For the creation of the Point Cloud, the parameters have been defined so that its accuracy is as great as possible, and the classification of the point cloud has also been performed so that the Pix4DMapper program can accurately identify roads, buildings, and vegetation.

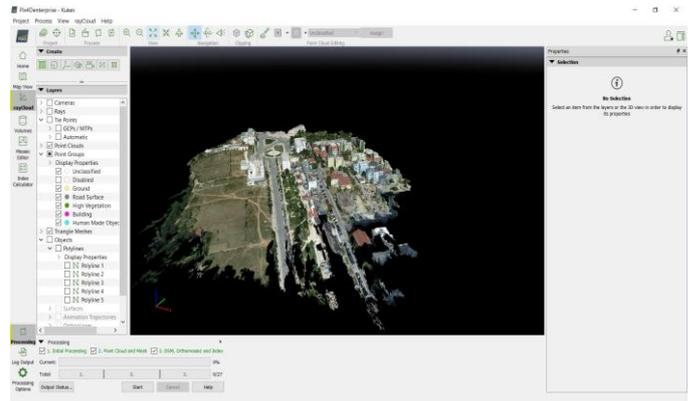


Figure 6: Point Cloud generated in Pix4D Mapper in Pix4 DMapper

### Orthomosaic

An orthomosaic is a photogrammetrically corrected image product created from a collection of images, where geometric aberration has been corrected and the images have been color balanced to produce a seamless mosaic dataset.

Orthophotos are commonly used in geographic information systems (GIS) as an "exact map" background image. A rectified image differs from "rubber-sheet" corrections, as the latter can accurately locate several points in each image, but "stretch" the area in between, so the scale may not be uniform across the image. A digital elevation model (DEM) is required to create an accurate orthophoto, as distortions in the image due to varying distance between the camera/sensor and different points on the ground must be corrected.

The software can display the orthophoto and allow an operator to digitize or place line work, text annotations, or geographic symbols (such as hospitals, schools, and fire stations).

Some software can process the orthophoto and automatically produce the line work.



Figure 7: Orthophoto of the selected urban area

### III. RESULTS AND DISCUSSIONS

In this section, we present the accuracy assessment and performance of UAV systems without using Ground Control Points in urban areas.

After the integration of Point Cloud in Pix4D Mapper, the points of the 6 check points were identified, and their coordinates were obtained. The following table shows the values of the obtained coordinates of the points with UAV Photogrammetry after processing the initial data.

**Table 2: Coordinates of 6 check points obtained from UAV Photogrammetry**

Point	N (m)	E (m)	H (m)
St1	4660241.726	534477.357	398.734
St2	4660158.278	534440.487	396.157
St3	4660273.853	534591.662	397.330
St4	4660194.705	534617.691	397.529
St5	4660108.142	534538.659	397.812
St6	4660171.442	534675.839	397.443

The position of the points was obtained by applying two methods: firstly, with using GPS and Total Station and secondly by obtaining coordinates of points using UAV Technology. In this study, we can see the difference between the coordinates of check points measured by GPS and Total Station and the coordinates of the same check points determined by drone is quite small. Horizontal accuracy is  $\pm 0.025m$  and vertical accuracy is  $\pm 0.035m$ .

**Table 3: Assessment of accuracy of using UAV Systems without GCP**

Point	$\Delta N$ (m)	$\Delta E$ (m)	$\Delta H$ (m)
St1	0.027	0.024	0.032
St2	0.016	0.033	0.043
St3	0.044	0.025	0.053
St4	0.022	0.036	0.048
St5	0.007	0.027	0.023
St6	0.023	0.003	0.028

### IV. CONCLUSION

In the pursuit of assessing the accuracy of UAV systems in urban areas without the traditional reliance on Ground Control Points (GCPs), this study has unraveled critical insights that contribute to the ongoing discourse on the efficacy and limitations of contemporary geospatial mapping methodologies.

The conclusions drawn from the comprehensive investigation shed light on various aspects, offering guidance for researchers, practitioners, and decision-makers seeking to leverage UAV technology in complex urban landscapes.

The results of the study showed that the UAV method is a viable alternative to traditional surveying methods for obtaining accurate coordinates in urban areas. However, it is important to note that the UAV method may require more specialized equipment and expertise and may be affected by factors such as atmospheric disturbances or image processing errors.

In conclusion, the use of UAV for surveying has the potential to provide accurate and cost-effective results for determining coordinates of control points in urban areas. However, further research and development are needed to refine the methodology and address potential challenges associated with the use of UAV for surveying.

The obtained results helped us determine the accuracy of this photogrammetric method in urban areas:

- The resolution of the orthophoto obtained from aerial image processing is very high. As a result, the accuracy of qualitative and quantitative data will be quite high, in the order of 3 cm.
- The use of UAVs without GCP seems to be a cost-effective result compared to traditional methods.

### REFERENCES

- [1] Balázsik V, Tóth Z, Abdurahmanov I “Analysis of Data Acquisition Accuracy with UAV.”*International Journal of Geoinformatics*, Vol. 17 Issue 1, p1-10. 10p, 2021.
- [2] Uysal M, Toprak A.S, Polat, N. “DEM Generation with UAV Photogrammetry and Accuracy Analysis in Sahitler Hill. Measurement,” 73, 539–543, 2015.
- [3] Przybilla H.J, Baeumker M. “RTK and PPK: GNSS-Technologies for Direct Georeferencing of UAV Image Flights.”*In Proceedings of the FIG Working Week 2020, Amsterdam, The Netherlands* p. 52, 2020.
- [4] Boon, M.A, Greenfield, R., Tesfamichael, S. “Unmanned Aerial Vehicle (UAV) Photogrammetry Produces Accurate High-Resolution Orthophotos, Point Clouds and Surface Models for Mapping Wetlands. S. Afr.”*J. Geomat.* 5, pp. 186, 2016.
- [5] Eker, R., Alkan, E., Aydin, A. “Accuracy Comparison of UAV-RTK and UAV-PPK Methods in Mapping Different Surface Types.”*Eur. J. For. Eng.* 7, 12–25, 2021.
- [6] Mulakala J. “Measurement Accuracy of the DJI Phantom 4 RTK & Photogrammetry.”, 2019.

- [7] Lee, I.S., Ge, L. "The Performance of RTK-GPS for Surveying under Challenging Environmental Conditions." *Earth Planets Space* 58, pp. 515–522, 2006.
- [8] Akgul, M., Yurtseven, H., Gulci, S., Akay, A.E. "Evaluation of UAV- and GNSS-Based DEMs for Earthwork Volume." *Arab. J. Sci. Eng.* 43, pp. 1893–1909, 2018.
- [9] Guo M, Sun M, Pan D, Wang G, Zhou Y, Yan B, Fu Z. "High-precision deformation analysis of yingxian wooden pagoda based on UAV image and terrestrial LiDAR point cloud." *Herit Sci.*;11(1):1, 2023.
- [10] Logothetis S, Delinasiou A, Stylianidis E. "Building information modelling for cultural heritage: a review." *ISPRS Ann Photogramm Remote Sens Spatial Inf Sci.*; II-5/W3:177–83, 2015.
- [11] Steffen, R., Foerstner, W. "On visual real time mapping for unmanned aerial vehicles." *IAPRS&SIS*, Vol. 37(B3a), pp. 57–62, 2008.
- [12] Eisenbeiss, H. "UAV photogrammetry. Diss. ETH No. 18515, Institute of Geodesy and Photogrammetry", ETH Zurich, Switzerland, Mitteilungen Nr.105, p. 235, 2009.
- [13] Seitz, S., Curless, B., Diebel, J., Scharstein, D., Szeliski, R. "A comparison and evaluation of multi-view stereo reconstruction algorithms." *Proc. IEEE Conf. CVPR '06*, Vol. 1, pp. 519-528, 2006.

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