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EVALUATING THE POTENTIAL OF UAV TECHNOLOGY FOR CADASTRAL MAP PRODUCTION

ISTRAŽIVANJE POTENCIJALA BESPILOTNIH LETJELICA U SVRHU IZRADE KATASTARSKIH PLANOVA

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ABSTRACT

This study investigates the use of unmanned aerial vehicles (UAVs) for geodetic surveys aimed at updating cadastral registers, which now function as geospatial databases. UAVs, using the aerial photogrammetric method, offer a cost-effective and efficient alternative to traditional airplane-mounted cameras. The research presents a comprehensive, step-by-step procedure for creating cadastral maps using UAV-acquired data, covering scope definition, preparatory work, flight planning, data processing, and final map production. The study includes an analysis of the resulting cadastral map and compares it with existing official maps to assess accuracy in determining parcel boundaries. The findings demonstrate that UAV-based surveys not only streamline the mapping process but also provide high levels of accuracy and reliability. This approach showcases the potential of UAV technology in modernizing cadaster systems, offering valuable insights into improving the precision and efficiency of geospatial data collection for land management and planning.

Keywords:** **Aerial photogrammetry, Unmanned aerial vehicle, Control point, Cadastral map, Survey

SAŽETAK

Ova studija istražuje upotrebu bespilotnih letjelica (UAV) za potrebe geodetskog premjera s ciljem ažuriranja katastarskih evidencija, koje danas funkcionišu kao geoprostorne baze podataka. UAV-ovi, korištenjem metode zračne fotogrametrije, predstavljaju isplativu i efikasnu alternativu tradicionalnim metodama snimanja pomoću kamera montiranih na avione. Istraživanje prikazuje sveobuhvatan postupak izrade katastarskih planova na osnovu podataka prikupljenih UAV-om, uključujući definisanje područja, pripremne radove, planiranje leta, obradu podataka i izradu konačnog plana. Studija sadrži analizu dobivenog katastarskog plana i poređenje s postojećim zvaničnim planom radi ispitivanja tačnosti određivanja međa parcela. Rezultati pokazuju da UAV snimanja ne samo da pojednostavljuju proces kartografisanja, već pružaju i visok nivo tačnosti i pouzdanosti. Ovaj pristup pokazuje potencijal UAV tehnologije u modernizaciji katastarskih sistema i nudi vrijedne uvide u poboljšanje preciznosti i efikasnosti prikupljanja geoprostornih podataka za upravljanje zemljištem i planiranje.

Ključne riječi: aerofotogrametrija, bespilotna letjelica, kontrolna točka, katastarski plan, premjer

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1 INTRODUCTION

Bosnia and Herzegovina has a long tradition of real estate registration. The earliest records of real estate registration date back to the period of the Ottoman Empire in the territory of Bosnia and Herzegovina. This system, known as the *tapu* system, remained in use until 1884 (Begić, 1999). The *tapu* system relied on descriptive definitions of parcel locations rather than precise measurements.

This system was replaced with the introduction of real estate records by the Austro-Hungarian Monarchy. Between 1880 and 1884, the entire territory of Bosnia and Herzegovina was surveyed, resulting in the creation of cadastral maps (Tuno et al., 2011; Tuno et al., 2015; Topoljak et al., 2017; Mulahusić et al., 2021). These maps did not include elevation data. Based on the cadastral maps and other collected data, the cadastral register of real estate and the land property register were established.

After the Second World War, a new phase of surveying in Bosnia and Herzegovina began, primarily using aerial photogrammetry (Topoljak et al., 2015). A significant portion of the territory was surveyed using this method, leading to the creation of updated cadastral maps and the establishment of a new cadastral register.

The cadastral register consists of interconnected graphic and descriptive data on real estate. Cadastral maps contain geospatial data of land parcels (Mulahusić et al., 2017; Mulahusić et al., 2022), all obtained through surveying. Graphical data are compiled into a topographic-cadastral map, which merges elements of both topographic and cadastral representations. These maps show ownership boundaries and depict the terrain in three dimensions.

Several surveying methods have been employed. The primary methods are based on standard surveying techniques, including reflectorless and prism-based measurements using total stations, GNSS RTK measurements, photogrammetry, and both airborne and terrestrial laser scanning. These techniques provide highly accurate data (Tuno et al., 2012; Mulahusić et al., 2016; Ćatić et al., 2022; Mulahusić et al., 2020; Ćatić et al., 2019).

UAVs are proving to be particularly valuable for updating cadastral records and mapping land parcels in both urban and rural environments. Studies such as Akdemir and Yıldız (2024) have demonstrated the potential of UAV-based methods for spatial data collection during cadastral updates, achieving high positional accuracy with significantly reduced fieldwork requirements. Similarly, Kersten et al. (2025) emphasized the technical viability of UAV photogrammetry for official cadastral tasks, noting its effectiveness in producing georeferenced orthophotos and 3D models. Petrov (2023) highlighted broader applications of UAVs in geodesy and cadastre, particularly in the context of land inventory and property boundary delineation. Furthermore, Manu et al. (2023) showcased how UAV photogrammetry can support cadastral inventory efforts on public rural land, offering reliable datasets for legal and administrative purposes.

Maps from the new surveys in Bosnia and Herzegovina were created using both terrestrial survey and aerial photogrammetry, with aerial photogrammetry being the dominant method (Tuno et al., 2017). This technique yields three types of information: visual, geometric, and physical. For geodetic professionals, geometric data are especially important for accurately representing buildings and surface details. To use photogrammetric images for measurement, the internal orientation of the recording camera must be known (Joksić, 1989). Until recent years, suitable aircraft for aerial photogrammetry were not readily available in Bosnia and Herzegovina. However, the emergence of unmanned aerial vehicles (UAVs) has introduced new opportunities for their application in aerial photogrammetry, particularly in the field of cadastral surveying. These technological advancements signal a significant shift toward the modernization of cadastral workflows through drone-assisted methods. This study aims to explore the potential of UAV-based photogrammetry for the creation and updating of cadastral records in Bosnia and Herzegovina.

2 CADASTRAL MAP

A geodetic map is an accurate, undeformed representation of a small portion of the Earth's surface and the features located on it. It is produced at a specific scale. In Bosnia and Herzegovina, cadastral maps are most commonly created at scales ranging from 1:500 to 1:5000. These maps provide detailed information about features, their positions, and spatial relationships.

Geodetic maps are generally categorized into the following types (Tuno, 2009):

- Cadastral maps,
- Engineering maps,
- Thematic maps,
- Topographic maps and
- Topographic-cadastral maps.

A cadastral map is a graphical representation of real estate, including all structures permanently attached to the land. It displays property boundaries and buildings, representing the terrain only in a horizontal plane. These maps are essential for establishing and maintaining the cadastre of real estate, land property registers, land consolidation, and related activities.

Cadastral maps can be created in either analog or digital form. Analog geodetic maps were traditionally drawn on materials such as paper mounted on canvas, glass, or aluminum plates (Mulahusić et al., 2023; Tuno et al., 2024). Analog cadastral plans were created at scales of 1:2500, 1:1000 and 1:500. In contrast, a digital geodetic plan is a system composed of three main components: digital data, software, and hardware. Unlike analog maps, digital geodetic maps do not store rasterized images; instead, they store structured spatial data (Tuno, 2009).

2.1 Creating a digital cadastral map

To create a cadastral map, the terrain must first be surveyed. Aerial photogrammetry, combined with the GNSS method for defining control point networks, is an efficient technique. With advancements in GNSS (Global Navigation Satellite Systems), INS (Inertial Navigation Systems), digital cameras, and the emergence of unmanned aerial vehicles (UAVs), UAVs have become increasingly valuable in photogrammetry (Kolarek, 2010). The first step in aerial photogrammetric surveying involves marking orientation points, followed by determining their coordinates using GNSS or terrestrial methods (Figure 1).

Figure 1. Establishment of control points and orientation markers.

UAVs are effective for specific types of surveying, offering significant cost reductions compared to traditional aerial methods. They are more efficient than airplanes, with several advantages, including the ability to use smaller runways, fly at slower speeds for surveying smaller areas, and operate independently of adverse weather conditions such as clouds or fog. However, optimal weather conditions are still preferred for the best results (Mulahusić et al., 2022). UAVs are controlled via a remote controller, making them highly versatile for surveying purposes. The aerial photogrammetry process included UAV flight planning in the DJI GO 4 application (Figure 2), followed by terrain imaging conducted with the DJI Mavic Air drone (Figure 3). Using UAVs for cadastral map creation significantly streamlines and accelerates the process of collecting data for establishing a real estate cadastral register.

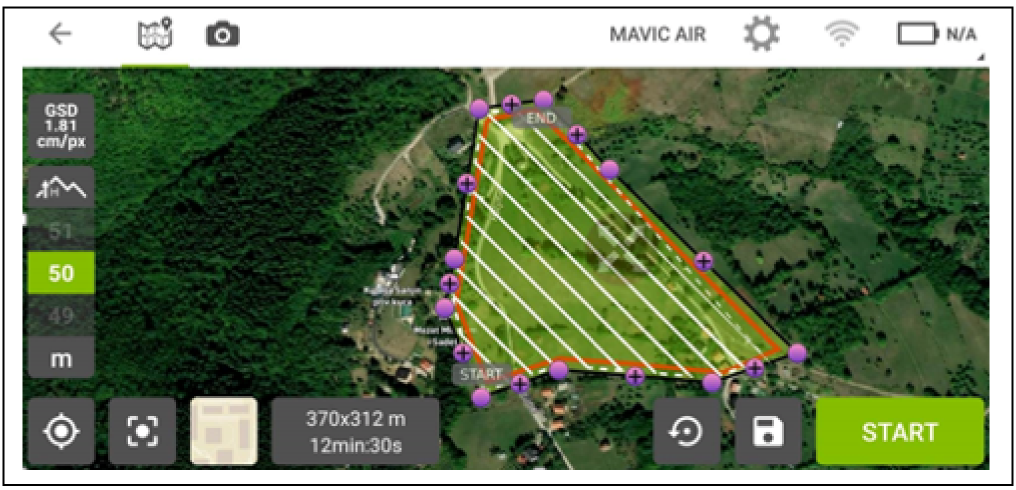

Figure 2. UAV flight planning for aerial survey in the DJI GO 4 application.

Figure 3. DJI Mavic Air drone alongside its remote controller.

The cost of using UAVs for aerial photogrammetry is lower than traditional aircraft-based methods, making them a more economical option. Additionally, aerial photogrammetry is much more efficient than terrestrial surveying methods. Software can be used to define flight parameters (such as altitude, overlap, and speed) and determine the UAV's flight path. The data obtained from the aerial survey—such as point clouds, contour lines, 3D terrain models, and orthophotos (Figure 4) — can then be used to create a cadastral map. The cadastral map (Figures 5 and 6) was created using AutoCAD software, based on the results of the aerial photogrammetric survey combined with supplementary field activities. These activities included additional control measurements and terrestrial surveying to capture areas obscured or insufficiently represented in the aerial images, such as regions covered by dense vegetation, shadows, or poorly exposed photographs.

Figure 4. Ortophoto.

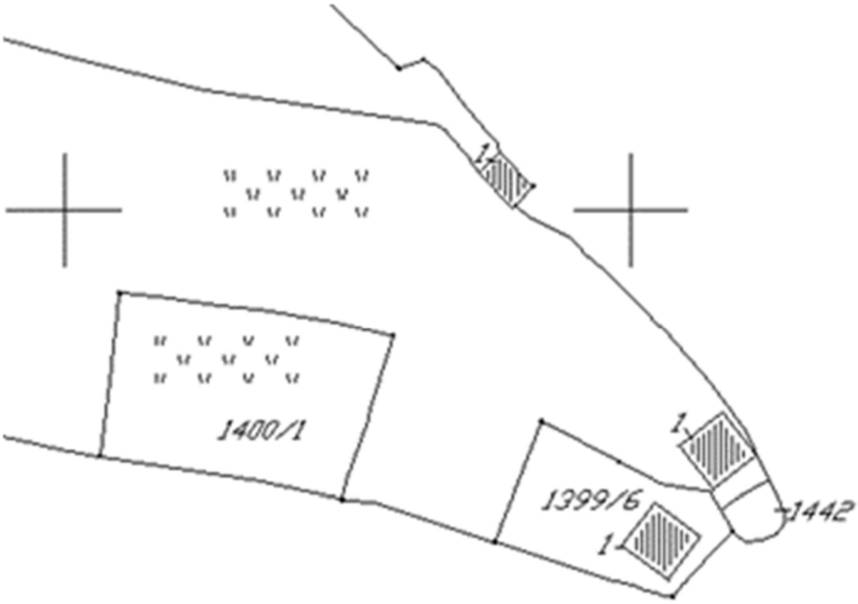

Figure 5. Cadastral map showing terrain representation in a 2D plane.

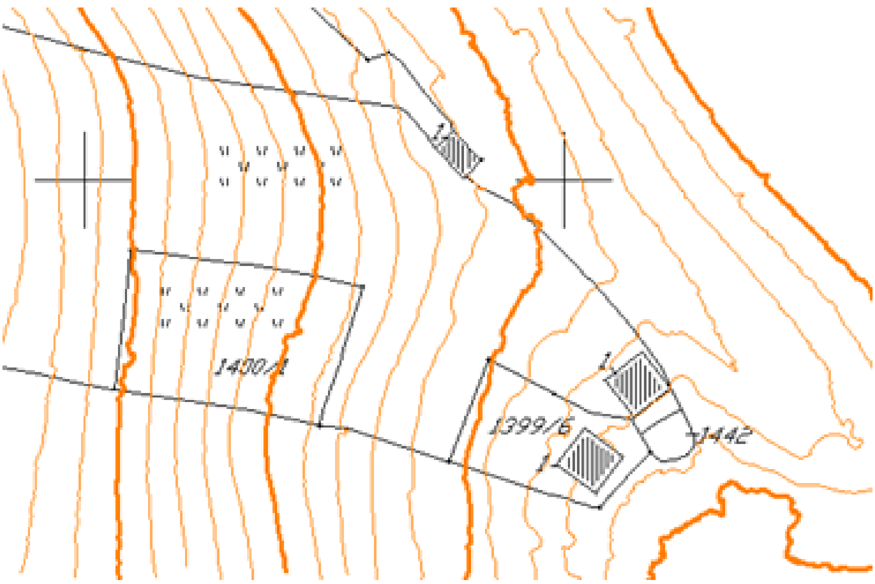

Figure 6. Cadastral-topographic map showing terrain features and property boundaries.

The creation of the map follows the guidelines set forth in the Rulebook for the preparation of maps and area calculations issued by the Republic Administration for Geodetic and Real Property Affairs of the Socialist Republic Bosnia and Herzegovina. The map is typically drawn at a scale of 1:2500. During this process, parcel boundaries are drawn, along with buildings, parcel numbers, vegetation symbols, and hatching to indicate building structures. Once all features have been mapped, an appropriate out-of-frame content is added to the digital cadastral map.

3 RESULTS AND DISCUSSION

The test area is located within the municipality of Centar Sarajevo, specifically in the cadastral municipality of Nahorevo. The existing digital cadastral map sheet NAHOREVO 85 (scale 1:2500) served as the basis for analyzing the created digital cadastral map.

The analysis was carried out in three variants:

- Variant 1: Analysis of the coordinates of corresponding detailed points
- Variant 2: Analysis of distances between terrain points and the created digital cadastral map
- Variant 3: Analysis of control point coordinates

For the first variant, the coordinates of corresponding detailed points were determined. Discrepancies in coordinates between the points obtained from the photogrammetrically generated digital cadastral map and the corresponding points (y_i, x_i) from the official cadastral database were calculated (Table 1). These values were then compared to the recommended allowable errors specified in the Rulebook for the Creation of Maps and Calculation of Areas, defined as:

$\Delta = 0.3 \text{ mm} \cdot M,$

where M is the scale denominator of the analog cadastral map (official digital cadastral maps were generated by digitizing the analog maps).

Table 2
Analysis of coordinate differences for corresponding detailed points

Point number *i*	**Differences along the *x* axes** Δx **[m]**	**Differences along the *y* axes** Δy **[m]**
1	-1.511	-0.346
2	-0.576	-0.919
3	-0.431	0.048
4	-0.670	0.038
5	-1.043	-1.644
6	0.117	-0.076
7	-0.383	-0.314
8	0.172	0.209
9	-1.747	-0.339
10	-2.515	0.999
11	-1.050	-0.145
12	-1.876	2.031
13	-1.832	-1.231
14	-1.418	0.172
15	-1.018	0.069

Significant number of detailed points revealed differences larger than 0.8 m, which is unsatisfactory.

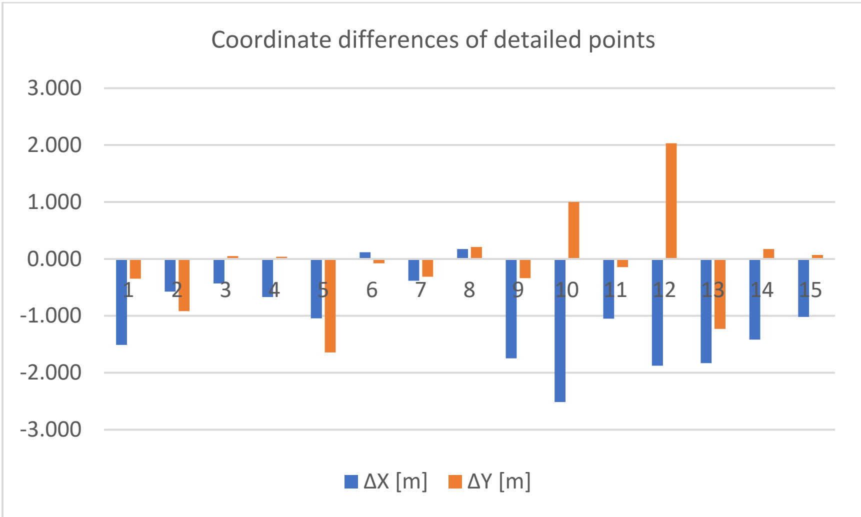

Figure 7. Diagram of differences between corresponding detailed points.

The values in Table 1 and Figure 1 clearly indicate that many of the detailed points do not meet the acceptable positional accuracy standards. This numerical evaluation prompted the need for visual and field checks. The terrain checks revealed discrepancies between the positions of the detailed points on the base map and their actual positions on the terrain. As a result, this analysis is deemed unreliable.

The next analysis (Variant 2) involved examining the distances between detailed points on the terrain and those on the created digital cadastral map, focusing solely on the distances between detailed points of buildings.

Table 2
Analyzing differences of distances of detailed points.

Distance number	Differences [m]
D1	0.045
D2	0.051
D3	0.047
D4	0.027
D5	0.029
D6	0.046
D7	0.013
D8	0.032

In the test area, dimensions of four buildings were measured both on the terrain and on the newly created cadastral map. During the analysis, differences between the terrain-measured values and the values obtained from the map were calculated. The range of these differences was found to be between 1 cm and 5 cm. These values were then compared to the allowable values specified in the Rulebook, and it was determined that the measured values were below the defined threshold (0.8 m).

The most important analysis (Variant 3) involved examining the coordinates of the control points. The horizontal positional accuracy of cadastral map was evaluated with original coordinates of geodetic points (y_i, x_i) as the reference values, and coordinates on cadastral map ($y_i^{cp.}$, $x_i^{cp.}$) as measured values.

Table 3 shows the quality of cadastral map, evaluated on the basis of differences between transformed and reference coordinates along y and x axes, $dy_i = y_i - y_i^{cp.}$, $dx_i = x_i - x_i^{cp.}$, and remained positional distortions $d_{yx} = \sqrt{dy^2 + dx^2}$.

The root-mean square error (*RMSE*) was calculated using a formula:

$$RMSE_r = \sqrt{\frac{1}{n}\sum_1^n dy^2 + \frac{1}{n}\sum_1^n dx^2} = \sqrt{RMSE_y^2 + RMSE_x^2}. \tag{1}$$

Table 3
Differences of coordinates and positional errors

Point number	**Differences of coordinates**		**Positional errors**
	d_y [m]	d_x [m]	d_{yx} [m]
K1	0.034	0.014	0.027
K2	0.014	0.029	0.019
K3	-0.020	-0.019	0.021
K4	-0.040	-0.055	0.037
K5	-0.022	-0.025	0.032
K6	0.033	-0.028	0.038

Table 4
Statistics of positional errors in the created cadastral map

Statistical indicator	d_y	d_x	d_{yx}
Minimum [m]	0.014	0.014	0.020
Average [m]	0.000	0.014	0.014
Maximum [m]	0.040	0.055	0.068
***RMSE* [m]**	0.029	0.031	0.042

These values were evaluated against the allowable threshold defined in the Rulebook. All measured values were below the specified limit of 0.2 meters. For all points, the remaining positional distortions were within the acceptable range. The smallest distortion was recorded at point K2, while the largest was at point K6. The graph in Figure 2 presents the calculated values of the remaining positional distortions.

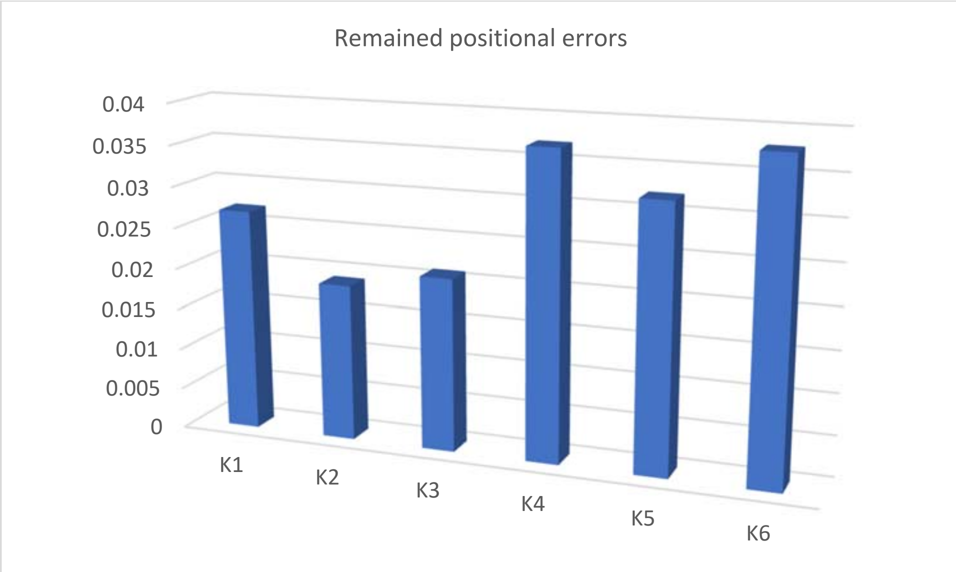

Figure 8. Diagram of remained positional errors of control points on the cadastral map.

4 CONCLUSION

This research clearly highlights the presence of non-uniform positional errors in characteristic points on the cadastral map created through aerial photogrammetric surveying using unmanned aerial vehicles (UAVs). The analysis was conducted in a small test area using three different variants.

The results from the first method were found to be unreliable, as the differences in coordinates exceeded the allowable limits. These discrepancies are primarily due to the displacement of detailed points, where the actual property boundaries captured by the photogrammetric survey often do not align with those recorded in the official cadastral database.

In contrast, the results from the second method were accurate, with all distance differences falling within the permitted range. The third method also produced reliable results. Therefore, the outcomes of the second and third variants can be considered valid and trustworthy.

The cadastral map created during the research demonstrated satisfactory accuracy. The study confirms that UAVs can effectively be used for aerial photogrammetric surveying in the production of cadastral maps. This method has proven to be not only reliable but also significantly faster than traditional terrestrial surveying techniques.

Surveying with UAVs is both economical and efficient. The application of aerial photogrammetry using UAVs has demonstrated strong potential for the creation of accurate digital cadastral maps. Moreover, the integration of modern digital photogrammetric methods introduces new possibilities by enabling faster, more cost-effective, and technologically advanced procedures based on digital techniques.

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