ACCURACY ANALYSIS OF THE APPLICABILITY OF UAVs IN CADASTRAL SURVEYS

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Summary: *In the last several years, the application of Unmanned Aerial Vehicles (UAV) undoubtedly has an ever-growing trend. What was previously limited to military use only, today is increasingly turning to civilian use. This paper analyses the possibility of using unmanned aerial systems in cadastral surveys. For that purpose, a survey has been conducted on a test field near the city of Novi Marof in the Republic of Croatia. Selected parcels were measured both with the GNSS RTK method, utilizing a receiver Stonex S9IIIN Plus and with a Topcon Falcon 8 UAV. The basis for the analysis and result interpretation represented the parcel boundaries break point coordinates obtained by the GNSS RTK measurements and the coordinates obtained from the Digital OrthoPhoto map (DOP) generated from UAV data. Furthermore, the analysis of the computed parcel areas was performed.*

Keywords: *UAV, GNSS RTK, cadastral survey, parcel boundary coordinates, parcel area*

1. INTRODUCTION

Today’s cadastral surveys are mostly based on the utilization of total stations and GNSS (Global Navigation Satellite System) receivers. These methods are highly efficient in precise and accurate measurements of relatively small number of discrete points of objects of interest. Contrary, photogrammetric approaches are characterized by vast data quantity, large area measurements and a variety of applicable sensors. In the last several years, the application of Unmanned Aerial Vehicles (UAVs) undoubtedly has an ever-growing trend. The demand for fast and effective measuring systems emerges. However, UAV surveys aren’t recognized as a potential in cadastral applications.

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In this paper the authors investigate the possibility of using UAVs and photogrammetric methods in cadastral surveys by comparing to the conventional cadastral surveying method utilizing GNSS RTK (Real Time Kinematic).

2. METHODOLOGY AND DATA ACQUISITION

With the aim of obtaining quantitative measures of the accuracy of the UAV surveying method in cadastral surveys both surveying methods have been applied on a test field near the city of Novi Marof in the Republic of Croatia (Figure 1). The test filed includes cadastral parcels 786/56 and 671 in cadastral municipality Donje Makojišće of the Regional Cadastral Office Varaždin, branch Office Novi Marof. The terrain configuration is uniform, without any significant height changes, and with an open horizon across its entirety. All parcel boundary break points are visible and during UAV survey were marked with artificial targets (Figure 3, left).

Figure 1. Overview of the test area in the cadastral municipality Donje Makojišće in Croatia [1]

As stated before, the test filed was measured with two surveying methods. The GNSS RTK survey was performed utilizing Stonex S9IIIN Plus GNSS receiver with Stonex S4 controller (Figure 2, left) and connecting to the High Precision Positioning Service (VPPS) of the Croatian Positioning System (CROPOS) which guarantees horizontal accuracy of 2 cm and vertical accuracy of 4 cm [2], [3]. The survey was conducted according to cadastral surveying standards defined by the Technical specifications of the State Geodetic Administration (SGA) of the Republic of Croatia [4].

The UAV surveying was conducted utilizing Topcon Falcon 8 UAV with a digital camera Sony Alpha 7R (Figure 2, right). The test area was measured in one 3-minute flight with an average flight height of 60 m during which 74 RGB images were collected. Prior to field measurements all relevant legal requirements, regarding the obtainment of required flight permits and approvals of authorized institutions, have been fulfilled.

Figure 2. Utilized measuring systems: Stonex S9IIIN and Stonex S4 controller (left) [5] and Topcon Falcon 8 UAV (right) [6]

Figure 3. Placed artificial targets (left) and GCPs (right) in the test filed [7]

Furthermore, before the UAV survey, eight Ground Control Points (GCPs) have been defined and measured in the test filed (Figure 3, right). Their coordinates were measured utilizing the above described GNSS RTK method and instruments. All GCPs were regularly spatially distributed across the test area.

3. MEASUREMENT RESULTS

According to the above-mentioned methodology, the GNSS measuring data were processed and resulted with horizontal coordinates (E_{GNSS}, N_{GNSS}) of all 22 parcel boundary break points (Table 1). The coordinates are defined in the official system/map projection of the Republic of Croatia, i.e. HTRS96/TM (EPSG code: 3765). Obtained parcel boundary coordinates are visualized on Figure 4 (left).
From the acquired 74 RGB images, a Digital OrthoPhoto map (DOP) of the test area has been generated. Tie-point on all images were automatically determined using Structure from Motion (SfM) algorithm. Photo-triangulation method with self-calibration, based on the defined tie-points and GCP coordinates, resulted in the final DOP of the test area (Figure 4, right) with a spatial resolution of 0.01 m. The entire image orientation and DOP map generation process was performed using Agisoft Photoscan software. Figure 4 depicts a comparative view of the results of the GNSS RTK survey and the UAV generated DOP map of the test field. At first glance one can immediately notice a tremendous difference in the amount of the obtained data from the two mentioned methods.

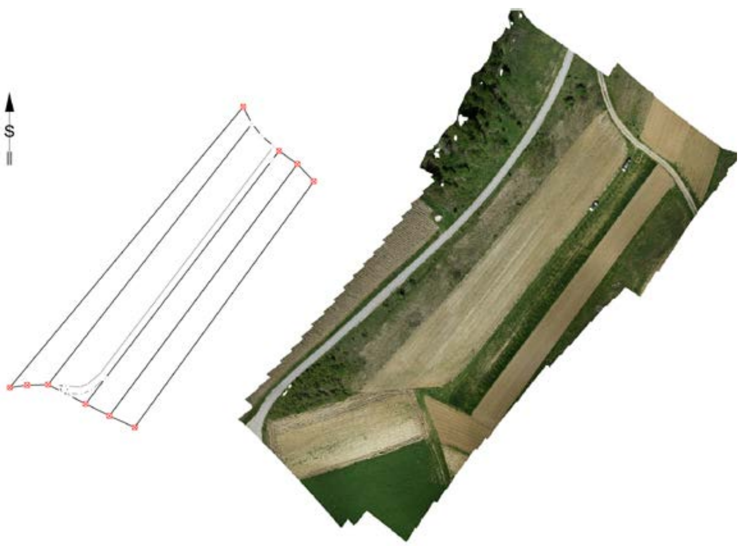

Figure 4. A comparative overview of the resulting GNSS RTK survey data (left) and UAV generated DOP map (right) [7]

In addition, Table 1 provides an overview of the final measurement results, i.e. boundary break point coordinates of the measured parcels determined by the GNSS RTK surveying method (E_{GNSS}, N_{GNSS}) and coordinates extracted from the UAV generated DOP map (E_{UAV}, N_{UAV}). In total, 22 points were selected, and their coordinates represent the basis for the accuracy analysis discussed further in text.

Table 1. Parcel boundary break point coordinates [7]

Point ID	GNSS RTK survey		UAV survey	
	E_{GNSS} [m]	N_{GNSS} [m]	E_{UAV} [m]	N_{UAV} [m]
1	485405.85	5113483.57	485405.83	5113483.58
2	485323.41	5113375.36	485323.37	5113375.34
3	485344.28	5113365.30	485344.28	5113365.30
4	485307.43	5113383.61	485307.42	5113383.65
5	485298.45	5113383.39	485298.45	5113383.45
6	485291.07	5113382.36	485291.09	5113382.40
7	485321.50	5113379.55	485321.48	5113379.54
8	485325.92	5113381.38	485325.89	5113381.38
9	485398.55	5113490.02	485398.55	5113490.03
10	485394.27	5113495.15	485394.27	5113495.12
11	485390.57	5113502.46	485390.55	5113502.41
12	485321.02	5113382.60	485321.00	5113382.59
13	485324.34	5113383.97	485324.32	5113383.98
14	485329.51	5113388.32	485329.45	5113388.27
15	485331.70	5113386.24	485331.63	5113386.18
16	485403.60	5113485.56	485403.58	5113485.57
17	485402.77	5113479.52	485402.75	5113479.53
18	485316.49	5113378.93	485316.49	5113378.92
19	485316.12	5113380.00	485316.12	5113380.00
20	485315.06	5113383.04	485315.04	5113383.10
21	485312.20	5113383.26	485312.16	5113383.35
22	485313.12	5113380.67	485313.11	5113380.68

Projection: HTRS96/TM; EPSG code: 3765

4. RESULT ANALISYS

Based on the defined methodology and the obtained point coordinates, an accuracy assessment has been conducted. Parcel boundary break point coordinates measured with the GNSS RTK method (E_{GNSS}, N_{GNSS}) have been taken as reference values and coordinates extracted from the DOP map obtained by the UAV method (E_{UAV}, N_{UAV}) as test values. By subtracting UAV from GNSS RTK data corresponding residuals of individual coordinate axes (ΔE and ΔN) are calculated and their distribution analysed using histograms with a superimposed curve of normal distribution (Figures 5 and 6).

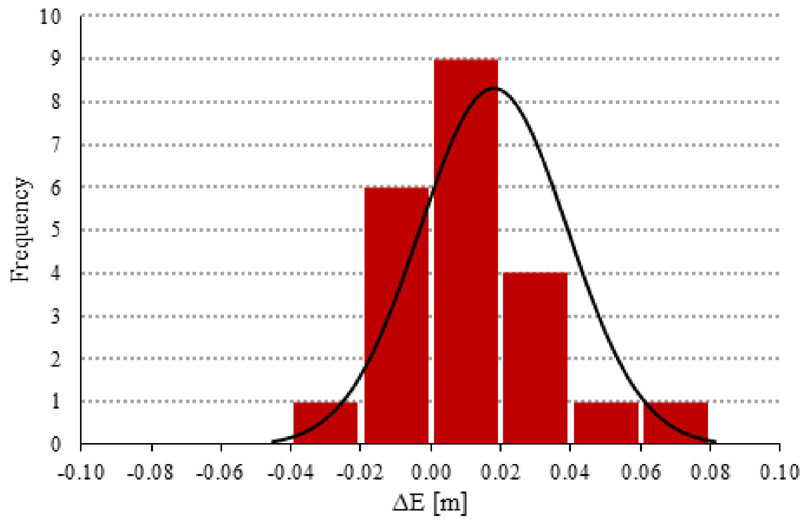

Figure 5. Histogram of residuals (E axis)

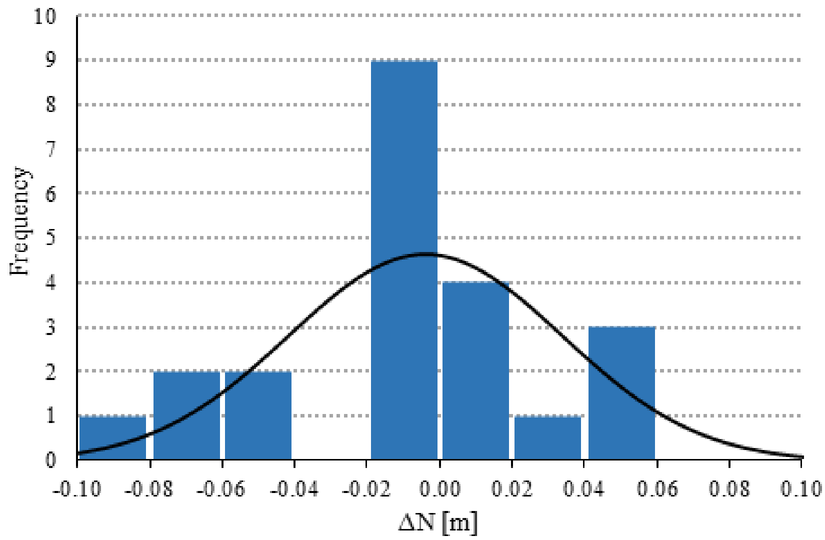

Figure 6. Histogram of residuals (N axis)

Furthermore, based on the obtained datasets, and as a supplement to the given residual distribution, fundamental statistical parameters (minimum, maximum, arithmetic mean and standard deviation) are calculated and are given in Table 2.

Table 2. Fundamental statistical parameters of the obtained datasets [7]

Statistical parameter	**ΔE** [m]	**ΔN** [m]
Minimum	–0.02	–0.09
Maximum	0.07	0.06
Arithmetic mean	0.02	0.00
Standard deviation	0.021	0.038

To derive basic conclusions and asses the correctness of conducted measurements, the obtained results are compared to accuracy requirements and standards of cadastral surveys defined and regulated by the SGA [8]. The SGA requires that the maximum deviation of measured parcel boundary break point coordinates between two independent measurements, outside city limits, is 0.2 m [8]. In this study, an average position accuracy of UAV data of 2 cm has been achieved. This result meets the legislation requirements. Therefore, the UAV surveying method described in this study, can be efficiently used in cadastral surveying applications.
Additionally, based on the obtained parcel boundary break point coordinates, areas of the measured parcels are calculated, both for GNSS RTK and UAV datasets, and given in Table 3. Those parcel areas are compared, and differences are calculated ($dA_{REF-GNSS}$ and $dA_{REF-UAV}$), to the reference areas given in the official cadastral records (A_{REF}). The State Survey and Real Property Cadastre Act [9] defines that the maximum area difference between official cadastral records and newly formed (measured) parcels is 20%. Accordingly, Table 3 shows the maximum allowed difference (Δ).

Table 3. Calculated parcel areas and corresponding differences [7]

Parcel ID	$\mathbf{A_{REF}}$ [m²]	$\mathbf{A_{GNSS}}$ [m²]	$\mathbf{A_{UAV}}$ [m²]	$\mathbf{dA_{REF-GNSS}}$ [m²]	$\mathbf{dA_{REF-UAV}}$ [m²]	$\mathbf{\Delta=20\%A_{REF}}$ [m²]
786/56	1730	1440	1438	290	292	346
671	2540	2339	2337	201	203	508

From the obtained results it can be noticed that the area criterion is fulfilled for parcel areas calculated from both datasets, i.e. the calculated area differences are smaller than the maximum allowed value. The difference between GNSS RTK and UAV dataset areas is 2 m^2.

5. CONCLUSION

The high efficiency, precision and accuracy of the application of the GNSS RTK method in cadastral surveying have been confirmed for over a decade. Although UAVs and photogrammetric method are used in many applications, their use in cadastral applications has never entered everyday routine surveys.

Based on the results of the conducted study, it is concluded that the position accuracy of coordinates obtained through a UAV survey meets the cadastral survey standard requirements. Furthermore, parcel areas, calculated based on the obtained coordinates, fulfil the defined area condition.
Finally, it can be concluded that cadastral data derived from the UAV survey fulfil all accuracy and legal requirements and can be used in addition to traditional surveying methods to generate and maintain cadastral data and maps.

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АНАЛИЗА ТАЧНОСТИ ПРИМЕНЕ БЕСПИЛОТНИХ ЛЕТЕЛИЦА У КАТАСТАРСКИМ ИЗМЕРАМА

Резиме: *Последњих неколико година несумњиво је растућа примена беспилотних летелица (УАВ). Оно што је пре било ограничено на војну употребу, данас се све више окреће цивилној употреби. У раду се анализира могућност примене беспилотних летелица у катастарским измерама. У ту сврху обављена је измера на тестном пољу код града Нови Мароф у Републици Хрватској. Одабране катастарске парцеле измерене су методом ГНСС РТК користећи уређај Стонекс С9ШН Плус и применом беспилотне летелице Топцон Фалцон 8. Координате ломних тачака међа катастарских парцела које су добивене мерењем ГНСС РТК-ом и координате добивене са дигиталне ортофото карте (ДОФ) из података снимљених беспилотном летелицом, били су основа за анализу и интерпретацију резултата. Поред тога, извршена је анализа израчунатих површина катастарских парцела.*

Кључне речи: *УАВ, ГНСС РТК, катастарска измера, координате међа катастарске парцеле, површина катастарске парцеле*