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Application of remote methods with unmanned aerial systems for the production of cadastral maps and cadastral registers on the territory of the Republic of Bulgaria

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Abstract

With the advancement of technologies, their mass application began, which can easily gather information about the characteristics of spatial objects from a given territory. Unmanned aerial systems (UAS) are widely used in geodesy, GIS (mapping), security, aerial photography and video capturing, science and research, and others. Like any of the other geodetic technologies, aerial photogrammetric imaging through UAS cannot achieve 100% applicability in the rich variety of reality to be mapped. This does not mean that this technology cannot be applied to the needs of geodesy and cadastre along with traditional geodetic techniques for collecting spatial data, but that it is necessary to seek their combination for optimal and effective achievement of the set goals and objectives. In order to increase the degree of applicability of aerial photogrammetry with UAS, in particular for the needs of the cadastre, the characteristics of the technical means used for aerial photography, the preparation of specialists to reduce the subjective factor in mapping and the conditions preventing visibility to the objects of the cadastre influence the process. [9]

In recent years, various publications have presented results from the application of remote methods with unmanned aerial vehicles to produce a cadastral map and cadastral registers.

1. Introduction

With the increasing population, cities are constantly changing and developing. Therefore, it is difficult to monitor and control rapid changes in cities. Therefore, planning is very important in terms of controlling these dynamic cities and ensuring regular and planned settlements. However, buildings may not always be built in accordance with the plan and may be built against the zoning law. These structures, which are built against the plan, can distort the city's silhouette, cause unplanned construction and restrict people's access to some services. It is also important that the building detection process, which is needed in many areas from population movements to city development, from illegal building surveillance to casting extraction, is accurate and automatic. With the development of Remote Sensing and Geographic Information Systems (GIS), new methods have been used to detect such structures. One of these methods used is the detection of these structures with high resolution data. In this research, the building detection by using point clouds data obtained from Light Detection and Ranging (LiDAR) system with satellite images [20,28,29].

The creation of a cadastral map and cadastral registers for the entire territory of the country is a great challenge for the Agency for Geodesy, Cartography and Cadastre, set up at the beginning of the 21st century. The adopted concept in 2015 accelerates the process of creating CMCR for the whole country. Existing map materials (including the map of recovered property), classic data collection methods and remote methods are used for data sources.

Unmanned Aerial Vehicle (UAV) technology has become a commonly used tool for data acquisition in geospatial applications due to its ability to produce high spatial resolution images which facilitate the production of high-accuracy photogrammetric products such as maps, orthoimages, 3D models, Digital Elevation Models (DEMs) and point cloud. In addition, UAV technology provides a low-cost and flexible alternative to other remote sensing platforms, such as classical aerial photogrammetry and satellite platforms. UAVs are small in size, have autonomous vertical take-off and landing characteristics, have low site requirements, and have high flight safety performance [19,24,27].The utilisation of UAVs mounted with modern non-metric consumer-grade digital cameras is rising globally due to their affordability and ease of operation . A camera consists of an image plane and a lens, which provide a transformation between object space and image space. This transformation is affected by the characteristics of the camera. The commonly used non-metric consumergrade cameras are characterised by adjustable camera parameters such as principal distance and principal point, and their lenses have relatively large distortions compared to metric and survey-grade cameras. Low-quality lenses in non-metric cameras cause inconsistencies in the camera system, leading to systematic errors that impact UAV product quality [14,17,18, 23].

Other aspects that influence the accuracy of UAV-derived products include the flight parameters (flight height, direction, speed, and image overlaps) and Ground Control Points (GCPs) geometry. Whereas the user has flexibility over the flight parameters used during flight planning, limited UAV/camera options may be available. Optimising the user's available UAV/camera system is essential to achieving optimal accuracy. Applying precise camera calibration parameters for photogrammetric processing with non-metric cameras can help achieve this. Accurate camera parameters and lens distortions compensate for systematic errors in transforming points from object to image space, ensuring quality photogrammetric products. [14,21,25]

Digital image processing heavily relies on the connectivity of pixels, as it is a vital component for accurate object identification and analysis within an image. Grouping together pixels with similar features such as colour and intensity, allows for the formation of meaningful patterns or objects, which is essential for object recognition and segmentation. This approach is particularly valuable in photogrammetric imaging, video surveillance, deep learning as it facilitates the isolation of regions of interest and object tracking. Image smoothing is also a crucial aspect in enhancing visual quality by reducing noise and enhancing details, especially in applications such as aerial mapping, medical imaging, video compression, image resizing and computer vision. The absence of connected pixels and image smoothing would make image processing tasks more challenging and less reliable, making them fundamental to digital image processing and critical to various applications in diverse fields. [18,22]

2. Legal framework

The content, terms and conditions for the creation, maintenance and storage of the cadastral map and cadastral ones on the territory of the Republic of Bulgaria are determined by the Cadastre and Property Register Act [1] and by Ordinance RD 02-20-5 of 16 December 2016 [2]. Pursuant to Art. 36, para. 1 of the same ordinance:

The cadastral map and cadastral registers are created by merging data from:

1. cadastral plans of urbanized territories;
2. plans and maps approved under the Ownership and Use of Agricultural Lands Act (OUALA) and the Restoration of Ownership of Forests and Lands from the Forest Fund Act (ROFLFFA);
3. geodetic measurements;
4. regulation plans – in the cases under Art. 14, para. 1, item 4 of [2];
5. maps, plans and other documentation provided pursuant to Art. 30 of [2] by departments, regional and municipal administrations, legal entities and other registries.

3. Methods for creating a cadastral map and cadastral registers

3.1. Direct geodetic measurements

When there are no cadastral plans for an urbanized area or the content and accuracy of the existing ones does not meet the requirements for timeliness and/or accuracy, the cadastral map and cadastral registers shall be created with geodetic measurements. The regulatory requirements for carrying out geodetic measurements are set out in Annex No. 8 to Art. 36, para. 2 of [2]:

1. Geodetic measurements are carried out using technologies that provide data for determining geodetic coordinates of points of borders, with an accuracy higher than that specified in Art. 18, para. 4, item 1, respectively – Art. 18, para. 5, item 1 of [2], reduced three times.

2. Geodetic measurements are not the technologies for determining the coordinates of points by digitization (scanning and vectorization) of graphical plans and maps approved under the law.

3. Geodetic measurements can be made by:

a) total stations and technologies providing the requirements of item 1;

b) GNSS and technologies providing the requirements of item 1;

c) photogrammetric technologies providing the requirements of item 1;

d) combinations of the technologies listed above.

4. The total stations shall be subject to the following requirements:

a) accuracy of measured direction mR < = 5 mgon;

b) precision of measured length mS < = (10 + 10 S.10-6) mm, where S is the measured length in meters.

5. In total station measurements, the instrument is centred and horizontalised on a point on the geodetic base or at an appropriately selected location to determine its planning position through a free station with alignment. It is allowed to create secondary covered polygons at points of the geodetic basis, as well as to use rod points (up to two) defined by points of the geodetic basis. The planned accuracy of a point defined as a free station, or a point defined in a secondary polygon, must not exceed the permissible values defined in Art. 23, para. 11, item 2 of [2].

6. When measuring to the detailed points, the station is oriented to at least two points of the geodetic base at

two positions of the viewing tube except for the rod points if there is no possibility of two orientations.

Collimation error determined from orientation measurements must be less than 4 mgon. Measurement to a detailed point is done at one position of the viewing tube. The measurements end with a control measurement to one of the orientation points.

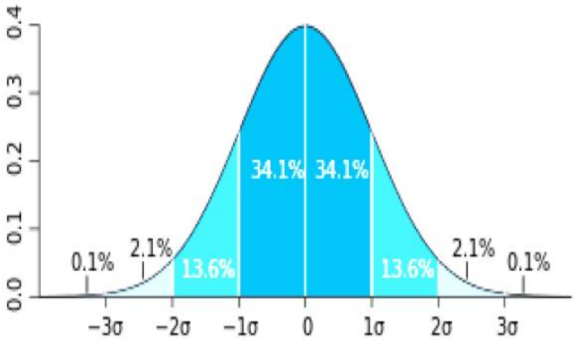

Figure 1. Graph of the normal distribution and the percentage of hits per random quantity of segments equal to the mean quadratic deviation [5]

To assess the accuracy of geodetic measurements in Bulgaria, the use of the least squares method was adopted, which was developed independently by Gauss and Legendre.

Figure 1 shows the graph of the normal distribution of errors and the percentage of the random values of the mean quadratic deviation. Here the problem when examining the normal distribution of errors is that only random errors are involved and one part of them, which are outside the range -3σ ÷ +3σ, is assumed not to exist.

3.2. Use of GNSS technologies

Determination of geodetic coordinates of GNSS boundary points shall be carried out in accordance with the requirements of Instruction No. RD-02-20-25 of 2011 on the Determination of Geodetic Points Using Global Navigation Satellite Systems [4] issued by the Ministry of Regional Development and Public Works, Chapter IV, Section III "Geodetic photographs".

According to Section III of the same instruction [4], the basic method for taking geodetic photographs is real-time kinematic (RTK) or post-processing kinematic (PPK). When precision by position and height of 10 cm (of a detailed point in the picture) and higher is required, all points are determined by fixed solutions [12,30,31,33].

The requirements for base stations are as follows:

1. the permissible distance to the base points is limited by the measurement method as follows:

a) RTK and PPK – according to Art. 12, items 2, 3 and 4 of [4];

b) simplified static and kinematic methods – according to Art. 13, item 1 of [4];

c) differential methods – up to 200 km;

2. in case GNSS infrastructure is used, it is permissible to apply data from real and virtual base stations.

Measurements of permanently marked points shall be carried out in accordance with Art. 31, para. 1 of [4], on non-durably marked points – in accordance with item 1 of the same instruction, but with a duration of 10 sec, on terrain and contour points, as well as on detailed points from water photographs – in accordance with item 1 [4], but with single measurements at rest or in motion.

Control is carried out at the permanently marked and nodal points depending on the GNSS methods applied, as follows:

1. with subsequent processing – by double stationing or by two base stations;

2. in real time – by double stationing. [4].

3.3. Use of photogrammetric technologies

For determining geodetic coordinates of points of borders with photogrammetric technologies, using manned aircraft, the requirements of Ordinance No. RD-02-20-16 of 2011 on the planning, implementation, control and acceptance of aerial surveying and the results of various remote methods for scanning and interpreting the ground surface [3], issued by the Ministry of Regional Development and Public Works, are applied. To determine geodetic coordinates of border points with photogrammetric technologies using unmanned aircraft (UA), the requirements of Implementing Regulation (EU) 2019/947, Delegated Regulation (EU) 2019/945 and the requirements of the General Directorate for Civil Aviation Administration apply.

With the entry into force of Regulation (EU) 2019/945 of the European Commission of 12 March 2019 on unmanned aerial systems and third country operators of unmanned aerial systems [10] and Regulation (EU) 2019/947 of the European Commission of 24 May 2019 [11], the Directorate General for Civil Aviation Administration (DG CAA) of the Ministry of Transport, Information Technology and Communications (MTITC) published a communication for UAS operators.

The highlights of this information message are:

The unrestricted UAS category is divided into three subcategories depending on the distance of the UAS from people and the weight of the UAS:

- Subcategory A1 it is allowed to fly UAS (not flying), over people, but not many people, and the UAS should have a maximum take-off weight of up to 500g;
- Subcategory A2 UAS flights near people are allowed, with a distance of at least 50 m, and the UAS should have a maximum take-off weight of up to 2 kg;
- Subcategory A3 UAS flights with a maximum take-off weight of up to 25 kg, away from people at a safe distance of at least 150 m from residential, commercial, industrial or entertainment areas, are allowed. [7]

The mandatory conditions for the operation of UAS in the unlimited category are as follows:

- The UAS must always be in the field of vision of the remote pilot;
- The height of the flight should not be more than 120 m from the ground surface
- A certain competence of the remote pilot is required for the respective subcategory;
- Using an UAS of the correct weight assigned to the relevant subcategory.

In the event that any of the conditions cannot be fulfilled, the operation shall be carried out according to the requirements of the specific category.

The UAS operator shall carry out a risk assessment of the UAS activity in order to obtain a prior operational permit issued by DG CAA. [7]

Persons intending to operate an UAS must register as an UAS operator, subject to certain conditions. The UAS operator is assigned a unique registration number after the registration is completed. With this number, the UAS operator should mark all UAS with which it will operate. Before each flight, the remote pilot should check for activated areas prohibiting UAS flights in the area to be flown. [7]

4. Classic photogrammetry and unmanned aerial systems

4.1. Basic concepts in the photogrammetry

The word photogrammetry is derived from the Greek words photos – light, gramma – recording and metreo – measuring and in a literal sense means – measuring records made with light, i.e. measuring photos. [14]

The methods used to create images of objects based on the properties of the single (separate) aerial image are called photogrammetric.

In these cases, the position of the points can only be determined in planning terms and it is impossible to determine the position of the points in altitude terms.

A full description of the shape, dimensions and spatial position of the sites from the area is possible using stereo-photogrammetric methods based on the use of a stereopair of aerial images. Their essence consists in the following:

Figure 2 shows two points in the space S_1 and S_2, from which two pictures P_1 and P_2 (from one stereopair are obtained, where the points from the area A and B are depicted as points a_1 and b_1 on the left photo – P_1 and a_2 and b_2 on the right photo – P_2.

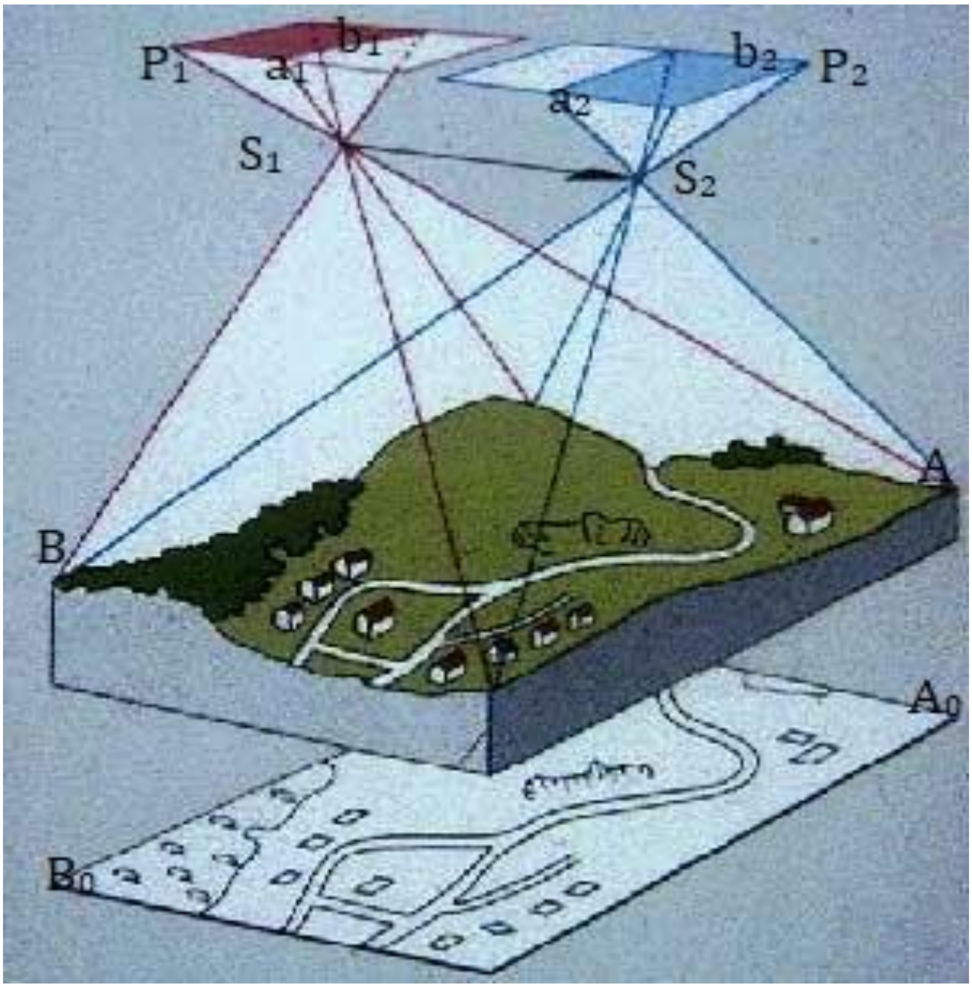

Figure 2. Stereopair photos, map and model of the area [16]

If the images P_1 and P_2 are placed in the position they occupied at the time of photography, the connection of the rays existing at the time of photography will be restored and by the intersection of the respective rays S_1a_1 and S_2a_2, S_1b_1 and S_2b_2, a so-called spatial (steroscopic) model of the object is obtained, which is similar to the object photographed from the area. The scale of the stereoscopic model is determined by the distance S_1S_2 between the tips of the connections and by changing it, it is possible to bring the built model to a predetermined scale. [6,15,34]

By rotating the model around the coordinate axes, it is possible to orient it to the generally accepted geodetic coordinate system.

To obtain a plan (map) of the area, it is sufficient to measure the spatial coordinates of points A, B and others on the stereomodel of the area and their design on the plane of the map (A_o,B_o).

It is obvious that the construction of a model of the area is possible only with the joint processing of a pair of overlapping pictures (stereopair). The presence of overlap between the pictures allows using stereophotogrammetry to develop high-precision triangular networks called phototriangular networks, which are divided into route and block networks.

The transformation of the coordinates of the points of the phototriangulation networks into a local one (Geodetic coordinate system) is done by using the so-called reference points, i.e. points whose coordinates are determined in the coordinate system of the phototriangulation network and through field measurements by classical geodetic methods are determined in the local (geodetic) coordinate system. [6,13,32]

4.2. Advantages and disadvantages of using UAS

4.2.1. Advantages of using UAS

- Ability to capture difficult-to-reach terrains such as landslides, slopes, dangerous terrains and inaccessible places;
- Measuring large objects in relatively less time than with classical methods;
- High resolution of the final product. For example, when inspecting facilities, GSD achieves accuracy of the order of 1-2 mm, sometimes less than 1 mm;
- The use of UAS can reduce the cost of the final product several times;
- Number of specialists required.

4.2.2. Disadvantages of using UAS

- The requirement for a serious computing resource;
- High qualification of specialists;
- Invisible areas;
- Restrictive regulations.

5. Application of UAS for the needs of the cadastre

The experiment involves photographing an urban area of 60 hectares, located on the territory of Southern Bulgaria. A total of 4,980 photos were registered from the 7 flights made.

7 control points are defined on the territory by GNSS measurements in RTK mode.

For aerial imaging, a professional photogrammetric system – DJI Matrice 300 with the following parameters was used:

– Camera – 45 Mpx
– GNSS receiver – RTK L1/L2
– Pixel Size on Terrain (GSD) –
1.5 cm@120m / 1.88 cm@150m / 2.51 cm@200m

The processing software used for the aerial capturing is DJI TERRA. The creation of a 3D model generally goes through the following steps:

- Orientation of the photos to each other;
- Orientation of the model in a real coordinate system through GCP;
- Creating a dense cloud of dots;
- Creation of a model of triangles;
- Creation of a surface model;
- Creation of an orthophotoplan.

The preparation of the geodetic photo as a sub-stage by the CMCR takes place in the environment of MKAD and CADIS.

The 3D model of the urbanized territory was prepared on the basis of a flattened 4980 pcs. of photos and the identical points extracted from them.

The absolute accuracy of georeferencing of the models was investigated by analyzing mean quadratic errors of used ground control points (GCP). The control points are evenly spaced on the territory of a settlement and measured with a dual-frequency GNSS receiver..

Table 1. The values from the direct field measurement compared to those derived from the model

	GNSS measurements		Digital model		Differences	
№	X	Y	X	Y	ΔX	ΔY
1	4206084,21	454095,98	4206084,20	454096,03	0,01	-0,05
2	4205841,77	453851,65	4205841,78	453851,67	-0,01	-0,02
3	4205380,74	453841,24	4205380,79	453841,28	-0,05	-0,04
4	4205542,38	453536,93	4205542,43	453536,90	-0,05	0,03
5	4205802,47	453588,70	4205802,50	453588,68	-0,03	0,02
6	4206234,81	453623,47	4206234,82	453623,44	-0,01	0,03
7	4205561,58	454065,29	4205561,63	454065,34	-0,05	-0,05

From the same geodetic basis, detailed points from the boundaries of land properties (permanently materialized) and buildings were also photographed. One of the objectives of the experiment is to compare the accuracy in the position of points on the boundaries of the cadastral objects, the coordinates of which are obtained from a digital model created by shooting with an unmanned aerial vehicle and from a polar photo carried out with a total station.

Two statistical lines were used in the comparison to assess accuracy:

$$\Delta x_i = X_i - x_i \quad (1)$$

$$\Delta y_i = Y_i - y_i \quad (2)$$

The total number of points in the comparison is 338 out of a total of 6,746. The minimum and maximum absolute value of the differences in X are 0.032 m and 0.186 m, and in Y – 0.047 m and 0.178 m. The mathematical expectation and the standard according to X and Y are respectively Mx = -0.07483, σx = 0,062338, My= -0.06192 and σy= 0,067047. Table 2 shows the data from the comparison of the coordinates of the detailed points.

Table 2. The values of the coordinates from the direct field measurement compared to those derived from the cross-sectional point model

	Digital model		Control measurement		Differences	
№	X	Y	X	Y	ΔX	ΔY
1	4206084,26	453952,55	4206084,36	453952,62	-0,10	-0,07
2	4206109,15	454028,54	4206109,26	454028,70	-0,11	-0,16
3	4206110,01	454036,60	4206110,12	454036,56	-0,11	0,04
4	4206111,11	454040,33	4206111,25	454040,34	-0,14	-0,01
5	4206120,58	454037,65	4206120,72	454037,67	-0,14	-0,02
6	4206117,51	454026,27	4206117,59	454026,36	-0,08	-0,09
7	4206136,79	454038,62	4206136,86	454038,71	-0,07	-0,09
8	4206141,71	454036,72	4206141,70	454036,69	0,01	0,03
9	4206128,58	454023,43	4206128,69	454023,48	-0,11	-0,05
10	4206132,76	454022,30	4206132,91	454022,31	-0,15	-0,01
11	4206131,51	454035,39	4206131,55	454035,50	-0,04	-0,11
12	4206057,16	453927,49	4206057,17	453927,59	-0,01	-0,10
13	4206128,54	454036,21	4206128,63	454036,31	-0,09	-0,10
14	4206107,03	454022,43	4206107,17	454022,42	-0,14	0,01
15	4206104,82	454013,16	4206104,92	454013,11	-0,10	0,05
16	4206113,83	454011,04	4206113,83	454011,05	0,00	-0,01
17	4206116,09	454020,31	4206116,17	454020,38	-0,08	-0,07
18	4206128,47	454005,68	4206128,47	454005,71	0,00	-0,03
19	4206058,91	453934,02	4206058,95	453934,03	-0,04	-0,01
20	4206116,84	454004,64	4206116,84	454004,74	0,00	-0,09
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			....			
			....			
320	4205905,23	453460,55	4205905,24	453460,67	-0,01	-0,12
321	4205902,26	453459,95	4205902,37	453460,03	-0,11	-0,08
322	4205896,10	453444,58	4205896,16	453444,75	-0,06	-0,17
323	4205904,68	453446,19	4205904,67	453446,18	0,01	0,01
324	4205908,13	453444,06	4205908,28	453444,05	-0,15	0,01
325	4205904,70	453443,47	4205904,82	453443,64	-0,12	-0,17
326	4205918,77	453459,73	4205918,92	453459,70	-0,15	0,03
327	4205909,55	453458,07	4205909,60	453458,14	-0,05	-0,07
328	4205920,41	453451,16	4205920,59	453451,21	-0,18	-0,05
329	4205920,67	453449,20	4205920,75	453449,29	-0,08	-0,09
330	4205914,15	453448,13	4205914,30	453448,22	-0,15	-0,09
331	4205911,20	453449,48	4205911,34	453449,65	-0,14	-0,17
332	4205926,82	453461,31	4205926,82	453461,32	0,00	-0,01
333	4205757,36	453559,93	4205757,39	453559,94	-0,03	-0,01
334	4205760,85	453560,68	4205761,04	453560,69	-0,19	-0,01
335	4205768,52	453560,42	4205768,68	453560,51	-0,16	-0,09
336	4205760,43	453543,76	4205760,54	453543,87	-0,11	-0,11
337	4205762,25	453536,00	4205762,23	453536,07	0,02	-0,07
338	4205756,58	453526,94	4205756,64	453526,93	-0,06	0,01

6. Conclusion

The results show the possibility of using unmanned aerial systems when creating a cadastral map and cadastral registers. In terms of accuracy – the results satisfy the requirements of Art. 18 of [2].

The merging of spatial technologies such as GNSS and the emergence of accessible platforms for the transmission of these technologies has opened up new opportunities for mapping and modelling cadastral boundaries. High-resolution images from unmanned aerial systems (UAS) can now be used to optimize the amount of field measurements and offers a more efficient solution with much more information for the needs of the cadastral map and the specialized cadastre.

By merging the digital models and the orthophoto jigsaw, it is possible to make a full detailed analysis of the source data for creating a cadastral map. This makes it possible to optimize as much as possible the estimate of the equipment, the necessary specialists, the exact location and the time needed to carry out additional field activities on the creation of a cadastral map. [8,26]

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References

1. Cadastre and Property Register Act. National Assembly of the Republic of Bulgaria. (2000). Retrieved from URL: https://www.cadastre.bg/sites/default/files/documents/regulation/6493/zkir-eng.pdf
2. Yakar, M., & Doğan, Y. (2017). Mersin Silifke Mezgit Kale Anıt Mezarı fotogrametrik rölöve alımı ve üç boyutlu modelleme çalışması. Geomatik, 2(1), 11-17.
3. Regulation No. RD-02-20-16 on the planning, implementation, control and acceptance of aerial imaging and the results of various remote methods for scanning and interpreting the earth's surface. National Assembly of the Republic of Bulgaria. (2011). Retrieved from URL: https://www.cadastre.bg/sites/default/files/documents/regulation/4752/naredla050811.pdf
4. Kanun, E., Alptekin, A., Karataş, L., & Yakar, M. (2022). The use of UAV photogrammetry in modeling ancient structures: A case study of “Kanytellis”. Advanced UAV, 2(2), 41-50.
5. Ivanova, Il. (2016). The Cadastre in Bulgaria. Intention and implementation. Sofia, Acmo Academic press
6. Petrov, D. (2011). Lectures on Photogrammetry, Shumen, Bulgaria, Faculty of Technical Sciences, Konstantin Preslavsky University of Shumen

7. Metodiev, K., (2021). Use of drones in the production of cadastral maps [PowerPoint slides]. Retrieved from URL: https://educad.geodesy-union.org/Drone_Cadastre_Krasimir_Metodiev_2021_11_28.pdf
8. Kirilova K.,& Yanchev K. (2020). Redefining the capabilities of the unmanned aerial system for the needs of the cadastre. MATTEX 2020 Conference proceedings, 2, 255-261
9. Hristozova, I., & Kalchev, I. (2016). Analysis and assessment of the applicability of aerial unmanned surveying in geodesy and cadastre, Journal of Geodesy, Cartography and Land Management, 1-2'2016, 26-41
10. European Commission Regulation (EU) 2019/945 of 12 March 2019 on unmanned aerial systems and third country operators of unmanned aerial systems. The European Commission. (2019). Retrieved from URL: https://eur-lex.europa.eu/legal-content/BG/TXT/PDF/?uri=CELEX:32019R0945&from=DE
11. European Commission Regulation (EU) 2019/947 of 24 May 2019. Directorate General for Civil Aviation Administration (DG CAA) at the Ministry of Transport. The European Commission. (2019). Retrieved from URL: https://eur-lex.europa.eu/legal-content/BG/TXT/PDF/?uri=CELEX:32019R0947
12. Stoykov, E. (2019) Methodology for surveying and tracing of objects by using GNSS, Annual of Konstantin Preslavski University of Shumen, IX E, 21-24.
13. Gholami, A. (2024). Exploring drone classifications and applications: a review. International Journal of Engineering and Geosciences, 9(3), 418-442. https://doi.org/10.26833/ijeg.1428724
14. Abeho, D. R., Shoko, M., & Odera, P. A. (2024). Effects of camera calibration on the accuracy of Unmanned Aerial Vehicle sensor products. International Journal of Engineering and Geosciences, 9(3), 314-323. https://doi.org/10.26833/ijeg.1422619
15. Akçay, Ö., Erenoğlu, R. C., & Avşar, E. Ö. (2017). The effect of jpeg compression in close range photogrammetry. International Journal of Engineering and Geosciences, 2(1), 35-40. https://doi.org/10.26833/ijeg.287308
16. Klein, A. (2005, May 4) Aerial Stereo Photography. Retrieved from: https://www.stereoscopy.com/faq/aerial.html
17. Yakar, M., Orhan, O., Ulvi, A., Yiğit, A. Y., & Yüzer, M. M. (2015). Sahip Ata Külliyesi Rölöve Örneği. TMMOB Harita ve Kadastro Mühendisleri Odası, 10.
18. Beşdok, E., & Çivicioğlu, P. (2023). Connected pixels-based image smoothing filter. Mersin Photogrammetry Journal, 5(1), 24-31. https://doi.org/10.53093/mephoj.1279877
19. Akça, Ş. (2024). Evaluating Urban Green Spaces Using UAV-Based Green Leaf Index. Mersin Photogrammetry Journal, 6(2), 52-59. https://doi.org/10.53093/mephoj.1536466
20. Ünyılmaz, C. N., Kulavuz, B., Bakırman, T., Bayram, B. (2024). Deep Learning Based Panchromatic2RGB Image Generation from VHR Images. Mersin Photogrammetry Journal, 6(2), 87-92. https://doi.org/10.53093/mephoj.1587804
21. Pırtı, A., Özateş, B., & Çakar, Ş. (2023). IRNSS (NavIC) uyduları ve sinyal yapıları. Geomatik, 8(1), 1-8. https://doi.org/10.29128/geomatik.980626
22. Efe, E., & Algancı, U. (2023). Çok zamanlı Sentinel 2 uydu görüntüleri ve makine öğrenmesi tabanlı algoritmalar ile arazi örtüsü değişiminin belirlenmesi. Geomatik, 8(1), 27-34. https://doi.org/10.29128/geomatik.1092838
23. Şenol, H. İ., & Gökgöz, T. (2022). İlkokul çocuklarının harita çizimi ve okuma becerilerini ölçme ve değerlendirmeye yönelik bir vaka çalışması. Geomatik, 7(1), 71-79. https://doi.org/10.29128/geomatik.859085
24. Kanun, E., Alptekin, A., Karataş, L., & Yakar, M. (2022). The use of UAV photogrammetry in modeling ancient structures: A case study of "Kanytellis". Advanced UAV, 2(2), 41-50..
25. Mohammed, O., & Yakar, M. (2016). Yersel fotogrametrik yöntem ile ibadethanelerin modellenmesi. Selcuk University Journal of Engineering Sciences, 15(2), 85-95.
26. Şahin, M. A. ., & Yakar, M. (2021). WebGIS technology and architectures. Advanced GIS, 1(1), 22–26. Retrieved from
27. Kuçak, R. A. (2022). The Feature Extraction from Point Clouds using Geometric Features and RANSAC Algorithm. Advanced LiDAR, 2(1), 15–20. Retrieved from
28. Karabacak, A., & Yakar, M. (2023). 3D Modeling of Mufti Abdullah Sıddık Mosque using Wearable Mobile LiDAR. Advanced LiDAR, 3(1), 01-09.
29. Yakar, M., Yilmaz, H. M., & Mutluoglu, O. (2014). Performance of photogrammetric and terrestrial laser scanning methods in volume computing of excavtion and filling areas. Arabian Journal for Science and Engineering, 39, 387-394.
30. Konukseven, C., Öğütcü, S. ., & Alçay, S. . (2022). GNSS Frequency Availability Analysis. Advanced Geomatics, 2(1), 14–16.
31. Karadeniz, B., Pehlivan, H. ., & Arı, B. (2023). Examination of the Performance of Precise Point Positioning Technique with Real-Time Products on Smartphones. Advanced Geomatics, 3(1), 33–39.
32. Unal, M., Yakar, M., & Yildiz, F. (2004, July). Discontinuity surface roughness measurement techniques and the evaluation of digital photogrammetric method. In Proceedings of the

20th international congress for photogrammetry and remote sensing, ISPRS (Vol. 1103, p. 1108).
33. Pulat, F., Yakar, M., & Ulvi, A. (2022). Yersel Fotogrametrik Yöntem Kullanılarak Fotogrametrik Yazılımların Karşılaştırılması: Hüsrev Paşa Camii Örneği. Türkiye Fotogrametri Dergisi, 4(1), 30-40.
34. Yilmaz, H. M., Yakar, M., & Yildiz, F. (2008). Digital photogrammetry in obtaining of 3D model data of irregular small objects. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37, 125-130.