Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Research on the possibility of using DJI Matrice 300 RTK with a Zenmuse P1 camera and DJI Mavic 3 Enterprise in work related to obtaining geometric data about buildings for the purpose of updating real estate cadaster and topographical database records

Marcin KARABIN[1], Wojciech OSTROWSKI[2], Magdalena PILARSKA-MAZUREK[3], Magdalena KARABIN-ZYCH[4] and Robert ŁUCZYŃSKI[5]*

Authors' affiliations and addresses:
[1] DSc., PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: marcin.karabin@pw.edu.pl,
ORCID: https://orcid.org/0000-0003-0812-3219

[2] PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: wojciech.ostrowski@pw.edu.pl,
ORCID: https://orcid.org/0000-0003-2103-1546

[3] PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: magdalena.pilarska@pw.edu.pl,
ORCID: https://orcid.org/0000-0001-9494-9863

[4] PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: magdalena.karabin-zych@pw.edu.pl,
ORCID: https://orcid.org/0000-0002-9522-0499

[5] PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: robert.luczynski@pw.edu.pl,
ORCID: https://orcid.org/0000-0001-5887-2176

***Correspondence:**
Marcin Karabin DSc., PhD., Warsaw University of Technology, Faculty of Geodesy and Cartography, Pl. Politechniki 1, 00-661 Warsaw, Poland,
e-mail: marcin.karabin@pw.edu.pl
tel.: +48-608-402-505

Funding information:
Grant no 16/ILGiT/2023 of the Scientific Council of the Civil Engineering, Geodesy and Transport Discipline of Warsaw University of Technology in 2023 "The use of the latest photogrammetric sensors in work related to obtaining geometric data about buildings for the purposes of updating cadastral databases and BDOT 500 database" - manager of project Marcin Karabin

Acknowledgement:
The authors would like to thank Mr Marek Ślązak – the Mińsk Mazowiecki district county surveyor for consent to perform experimental work in the district and his assistance in obtaining reference data.

How to cite this article:
Karabin, M., Ostrowski, W., Pilarska-Mazurek, M., Karabin-Zych, M. and Łuczyński, R. (2025), Research on the possibility of using DJI Matrice 300 RTK with a Zenmuse P1 camera and DJI Mavic 3 Enterprise in work related to obtaining geometric data about buildings for the purpose of updating real estate cadaster and topographical database records, *Acta Monstanistica Slovaca,* Volume 30 (2), 383-395

DOI:
https://doi.org/10.46544/AMS.v30i2.09

Abstract
In Poland, regulations on technical standards for performing geodetic surveying do not specify any technical conditions for performing UAV flights and surveys. The choice of surveying technology and ensuring the required accuracy is the responsibility of the licensed surveyor. In this article, the Authors presented the results of an experiment on the possibility of using data from a DJI Matrice 300 RTK with a Zenmuse P1 camera and a DJI Mavic 3 Enterprise to carry out work related to obtaining building corners data for the purposes of updating the real estate cadaster and topographical object database. Experiments were carried out in the area of the Chrośla cadastral district (Dębe Wielkie commune, Mińsk Mazowiecki district, Masovian Voivodeship, Poland). The necessary surveying activities included: measurement of GCPs using the GNSS-RTN method in relation to the ASG-EUPOS reference stations network, UAV photogrammetric surveys, field surveys of selected building corners (tachymetric method and points of the surveying control points network established for this task, using the GNSS-RTN technique), and computational and analytical activities. Images acquired from the DJI Mavic 3 Enterprise had a GSD of 2.85 cm, and from the DJI Zenmuse P1– 1.5 cm. Selected building corners were measured in the images using the space intersection method (104 corners covering the test area evenly), and the results were compared with the field measurement (GNSS-RTN + tachymetry). The obtained results indicated the possibility of using UAV technology as a fully alternative to traditional geodetic surveys - meeting the accuracy criteria resulting from applicable legal regulations (under specific conditions).

Keywords
unmanned aerial vehicle (UAV), real estate cadaster, building outlines

Introduction

The use of aerial data obtained from Unmanned Aerial Vehicles (UAVs), so-called drones, and photogrammetric measurements in typical surveying tasks is one of the most frequently discussed topics in the geodetic community. More and more scientific research is being conducted in this field. The authors of the publications propose the use of UAV technology in land consolidation works (Taszakowski J. et al., 2022; Doroż A. et al., 2023) to verify selected elements of the Polish base map (Brach M., Gąsior J, 2022), and also in works related to complex updating of the cadastral database (Bożek P. et al., 2023). The use of data obtained through measurements using UAVs is also becoming increasingly common in works related to updating geodetic databases in Poland (Bożek P. et al., 2023).

Reservations concern mainly the accuracy of the obtained data. In accordance with the regulation of the Minister of Development of August 18, 2020, on technical standards for performing geodetic surveying (...), (Regulation, 2020), *"field surveying should be performed using methods, techniques and technologies ensuring the achievement of specific accuracies in the location of field detail points and the fulfillment of specific conditions for performing such measurements. The choice of surveying technology and ensuring the required accuracy is the responsibility of the licensed surveyor"*. However, this regulation does not specify the technical conditions for performing UAV flights and surveys, recommendations regarding the parameters of the equipment used, or the method of confirmation of obtaining the appropriate surveying accuracy (technical report content). At the same time, economic aspects are the reason for constant pressure on surveyors to use UAV technology to obtain data, including that covered by the real estate cadaster database (EGIB) and the database of topographic features, the so-called BDOT 500, among others, in the field of geometric data regarding buildings.

In Poland, according to Regulation (2021a), buildings whose construction requires reporting or obtaining a building permission, and an as-built surveying inventory after their construction are subject to registration in the cadaster databases. In the current legal situation, many buildings do not require a post-construction geodetic inventory before they can be legally used by their owners. Such buildings, as well as buildings under construction, should be registered in the BDOT 500 – the database of topographic features. In the absence of the above-mentioned requirements, it is challenging to obtain individual data on such facilities and update both this database and the cadastral database in the field of land use. In this context, such "mass data acquisition" about building geometry (UAV measurement) is of significant practical importance, as it provides districts' authorities with geometric data about buildings, and also allows them to take legal actions aimed at updating the cadastral database in the of the type of land use (evidence obtained from UAV about the actual state of land development), which translates into the correct assessment of real estate taxes.

After years of rapid development of drones that could be used or were developed for photogrammetric and surveying applications, we can observe some stabilization as the UAVs likely reach their maturity phase in the technology lifecycle. However, variations among survey-grade UAV platforms are still visible and were the direct motivations behind undertaking research in this field. The proposed study aims to compare two multi-rotor platforms of different sizes and with different sensors. Still, both are equipped with RTK positioning and the ability to take oblique images efficiently ("smart oblique" mode). The use of oblique images not only increases the geometric accuracy of the study but also enables more effective registration of field details, such as building corners, which is crucial in this context.

The aim of the research is to evaluate data obtained with two UAVs, specifically the DJI Matrice 300 RTK equipped with a Zenmuse P1 camera and the DJI Mavic 3 Enterprise, and to assess the accuracy and usefulness of this technology for mapping building outlines. The work was carried out in part of the Chróśla cadastral district, located in the Dębe Wielkie commune, in the Mińsk Mazowiecki district, Masovian Voivodeship, Poland. As part of the experiment, the usefulness of these data was also assessed in the context of the possibility of obtaining data about buildings. In the case of photogrammetric data, a significant limitation in their use is, for example, natural terrain objects that obscure the building corners, which makes it necessary to support such measurements with classical surveys (additional workload). This problem should be largely solved by using the oblique imaging.

The state of research on the use of UAV technology in the real estate cadastre

Regarding accuracy research works, Plichta et al. (2017) examined the possibility of updating the cadastral database using UAV measurements. However, the authors focused on the possibilities of validating cadastral maps, as well as supplementing the cadastral database with additional elements related to buildings, such as terraces, stairs, etc., based on an orthophotomap created from nadir images from a UAV. This study does not provide numerical summaries confirming compliance in terms of data obtained from the UAV and from the control surveys made using GNSS RTN technology.

In fact, in the work of Plichta et al. (2017), no reliable data were used because the product itself, which is an orthophotomap, significantly limits the possibilities of obtaining geometric data regarding the building outlines, and in the presented work, also the additional elements of buildings that are adjacent to these buildings. The authors

(Plichta et al., 2017) wrote, "In relation to buildings with sloping roofs, the process of verifying the location, shape, and size of the object is difficult due to the frequent presence of eaves." In addition, the authors (Plichta et al. 2017), apart from the parameters of the UAV (multi-rotor with a Sony a6000 camera with a 19 mm fixed focal length lens), flight height (150m above ground level) and assumed overlap (front and side overlap equal 85% and 40%, respectively), did not provide any details regarding data processing.

Most of the published research works in the examined field were conducted on a small scale, i.e., they involved single objects or a few objects. Thus, in the work by Zrinjski et al. (2019), UAV technology was also tested, but only in the area of several cadastral parcels (22 boundary points), and the final product was an orthophotomap. Kędzierski et al. (2015) also focused on examining the possibility of using UAV data for updating the cadastre, and compared the obtained orthophotomap with the so-called base map. Unsatisfactory errors for buildings of 0.80 m were obtained. In research conducted by Manyoky et al. (2012), the test areas consisted of two cadastral parcels with buildings. In contrast, the work done by Mantey S. and Tagoe N. D. (2019) covered the boundary points of a single cadastral plot.

A study of UAV technology for updating cadastral databases covering a larger area was conducted by Šafář et al. (2021) for test areas in the Czech Republic, where the feasibility of using UAVs to collect data on buildings was confirmed. For the Bohy test object, a total of 63% of the 1,140 points measured by the traditional geodetic method could be identified in the point cloud. 80 % of the identified points met the accuracy requirement of 0.14m. However, the authors drew attention to the need to perform additional surveys using the classical geodetic method (based on the test areas, it was estimated that this would apply to an average of 25% of the total number of points to be obtained from a given area). For the Dlouhá Ves area, the comparison of the number of points that could be measured using UAV technology versus points from geodetic surveys yielded a 51.7% difference, which the authors attributed to the operators' limited experience in interpreting points in photogrammetric products.

Karabin et al. (2021) presented an experiment that covered a larger area. In this research, a UAV flight was conducted over the Podkampinos cadastral block, and nadir images were captured using a Sony A7R camera equipped with an FE 2/28 lens and a CMOS sensor (dimensions: 35.8 mm × 23.9 mm, resolution: 7380 × 4912 pixels, i.e., 36 MP). The images had a GSD of 0.03 m, the front overlap was 80% and the side overlap was 60%. 1660 images were collected and processed in the Pix4Dmapper program. 21 control points were established using GNSS-RTN technology. The planned image overlap of 80/60 ensured that each field point could potentially be observed in at least 6 images. Offset measurement of selected building corners was performed using GNSS-RTN technology (Kolida K9-T receiver and DistoD8 laser rangefinder). In the case of 78 points out of a total of 92 points (i.e. 85%), the differences obtained were: from 0.00 to 0.16 m; for 9 points out of 92 (10%), the differences obtained ranged from 0.17 to 0.25 m; for the remaining 5 points out of 92 (5%), the differences observed were not greater than 0.25 m, and for 3 of these 5 points the difference did not exceeded 0.30 m. The average error was m_X= 0.07 m, m_Y= 0.09 m.

On the other hand, Ożóg K. (2020) conducted research on the use of UAVs for assessing the accuracy of land boundaries. The research area covered over 50 ha (190 cadastral parcels) and was located in Sokołów Małopolski, Poland. After the research area was established and before determining the parcel's boundaries, UAV measurements were carried out, resulting in the creation of an orthophotomap with a pixel value of 7 cm. On this map, without marking the breakpoints of the parcel boundaries, an attempt was made to determine, as a result of the image interpretation, the location of the registered plots' boundaries' bend. Next, the boundaries of the registered plots were determined in the presence of the interested parties. With the use of wooden pegs of 25×25×250 mm, 338 boundaries' bending points were marked. The scribe lines of the registered plots' boundaries' bends were measured by the direct method in GPS-RTK technology with the Topcon GR-3 receiver. The next stage was to indicate on the wooden pegs the GCPs – a black and white four-point chessboard, of 100×100 mm, and for 100 points located in a compact group of signals 148×210 mm. The use of signals with different dimensions was aimed at examining the readability of characters for different pixel sizes and choosing the optimal one. The determination of the parcel's boundaries was carried out in October due to the increased presence of farmers in the area caused by the end of the farming season. Then, the flight and measurement were carried out using a UAV, which was based on 12 evenly spaced field points, measured directly. The square errors of the GCPs for X and Y coordinates were in the range of 0.03–0.14 m. Additionally, after adjustment, the result was checked on 20 independent, evenly distributed control points, obtaining differences not exceeding 0.10 m. Similar results were obtained by three points of the geodetic detailed network, which meets the legal parameters required by law.

A very similar experiment to this was presented and described in Soczek et al. (2024). The Authors compared two different UAVs equipped with oblique cameras. The differences between our research are mostly in the used UAVs and their equipment (one fixed-wing and one multi-rotor with a full-frame 42,4 MP camera vs. ready-made DJI UAVs with cameras). Another difference was that our article's measurements were conducted on UAV oblique images and point clouds generated based on the images, in comparison to the mesh model used by Soczek et al. (2024). The mean error for building corners measured on the mesh model from UAV images was 0,121 m and 0,022 m, depending on the used camera. In Libera et al. (2024), a similar experiment was presented, but it was extended to compare the measurement possibilities with existing databases. A total of 419 points were measured, 18 of which exceeded the permissible error in point position specified in the regulation [5].

The authors in the work Pyka et al. (2020) provide some recommendations regarding the use of UAV photogrammetry to measure the building contour itself. And so, as stated by Pyka et al. (2020), *"measurement of building contours should be approached with particular caution. Definitely, a stereo or multiple mono measurement on the images should be preferred. When proceeding to photogrammetric measurement of buildings, one should keep in mind that it is very difficult to make a complete measurement of contour breakpoints. In order to increase the completeness, it is recommended to use oblique images and align them together with vertical ones or cross-grid flight plan. The use of oblique images is not included in these recommendations".*

The measurement methodology used at the Chrośla cadastral district and the adopted experimental scheme

The research planned within the discussed scope was conducted in the Chrośla cadastral area, located in the Dębe Wielkie commune of the Mińsk Mazowiecki district in the Masovian Voivodeship, Poland, approximately 40 km from Warsaw. Chrośla is characterized by a relatively large test area, the buildings are located close to each other, and many newly built buildings can be found on this test area (Fig. 1).

Compared to the experiments whose results were presented in the previous chapter, where the authors use an orthophotomap (most often) or a point cloud, an important difference is that in this work, oblique images are used, the purpose of which was not to create an orthophotomap, but to do measurements on the images and generate a dense point cloud.

The photogrammetric products from which building corners were measured were: a block of aerial images (space intersection) and a point cloud. Data from field surveys performed using the GNSS-RTN/Total station technology were taken as the reference data for the analyses. In many studies, their authors use data from cadastral maps as reference data. The exception were the studies presented in Šafár et al. (2021) and Karabin et al. (2021), which used independent field surveys, which do not make comparisons dependent on the validity of the data presented on cadastral maps and eliminate the need to analyze the data sources that are the basis for registering objects (including buildings) on cadastral maps.

In the first stage, GCPs were established using the GNSS-RTN method in connection with the ASG-EUPOS national reference network (using the KOLIDA K-9T GNSS receiver). There were 31 control points marked in the field (Fig. 1a, a 10x10cm chessboard painted with orange paint or a watergate, also painted), which were measured 4 times (30 epochs of each measurement). In accordance with (Regulation, 2020), the results were averaged, and a control survey was also made at points of the national geodetic control points network, before starting the measurement. The deviations of the x and y coordinates permitted by law were obtained.

Fig. 1 Chrosla test area presented on aerial orthophotomap together with GCPs
Source: Own study

The images were acquired using two different UAVs: the DJI Mavic 3 Enterprise Multispectral RTK and the DJI Matrice 300 RTK, both equipped with the DJI Zenmuse P1 camera. Both UAV cameras collected data in the RGB spectrum. Camera parameters are presented in Table 1.

Table 1. Parameters of the cameras used in the experiment.

	DJI Zenmuse P1	DJI Mavic 3E
Focal length [mm]	35	12.29
Effective Mpx	45	20
Resolution [px]	8192 × 5460	5280 × 3956
Sensor size [mm]	35.9 × 24	17.3 × 13
Pixel size [um]	4.4	3.3
Focal length [mm]	35	12.29

Source: Tech spec.

The flights were conducted using the DJI Pilot 2 application. Using both UAV cameras, oblique images were acquired using the Smart Oblique function; however, this option works differently for each UAV. DJI P1 camera takes oblique and nadir images during one mission flight by setting the gimbal in five different positions (front, left, right, back, and nadir), thus the speed of the flight is relatively slow (2-3 m/s). At the edge of the mapping area, the number of taken images is reduced to only the gimbal positions that are useful in 3D area mapping, i.e., only images directed into the area and not outside the area. In the case of the DJI Mavic 3E, the gimbal automatically rotates in three directions (front, nadir, and back); thus, two perpendicular flight missions are necessary to acquire nadir and oblique images for the entire area.

The flight parameters for the UAVs were the same, i.e., the flight height was 90 m above ground level (AGL) and the front and side overlap were 80%. These parameters were chosen due to economic aspects (flying lower than 90 m is time inefficient) and the proposed overlap between the images should provide sufficient measurement possibilities. For these parameters, the spatial resolution of the images (GSD) of DJI Mavic 3E images was 2.42 cm for nadir and 3.42 cm for oblique images, and for the DJI P1 camera, 1.13 cm and 1.60 cm, respectively. In Table 2, the number of images, together with the acquisition dates, was presented.

Table 2. Summary of the images collected for the test area

Test area Chrośla	Acquisition date	Duration of acquisition	Number of images	GSD (nadir images) [cm]	GSD (oblique images) [cm]
DJI Mavic	09.07.2024	160 min	3029	2.42	3.42
DJI Matrice 300 with P1 camera	26.06.2024	145 min	4907	1.13	1.60

Source: Own study

For image aerial triangulation, GCPs were used. Aerial image triangulation was conducted using Agisoft Metashape Professional software. Both UAVs conducted their flights in RTK mode. All the GCPs were measured on the images, and firstly, all of them were used as Check Points. For the GCPs, X and Y errors were approximately. 2-3 cm; however, for the Z coordinate, the error was higher than expected (approximately 6-7 cm) and systematic. The systematic bias along the Z axis was probably caused by the self-calibration process without any GCPs and imperfection of the GNSS boresight self-calibration algorithm within the software. During the second adjustment of the camera calibration setting, the initial value of the Z offset was defined, which enhanced the final results of the image aerial triangulation. Thus, one GCP in the center of the test area was used to assess the initial Z offset (6 cm), and the rest of the GCPs were used as check points. Final accuracy of the aerial triangulation is presented in Table 3.

Table 3. Aerial triangulation results obtained for both cameras for the test area

Test area – Chrośla	X error [m]	Y error [m]	Z error [m]
DJI Mavic E	0.021	0.033	0.044
Zenmuse P1 camera	0.016	0.025	0.041

Source: Own study

In the next step, a control survey of selected building corners was performed using the tachymetric method (reflectorless measurement with a Leica TCR307 total station) with a control point network set using the GNSS-RTN technique (KOLIDA K-9T GNSS receiver) in connection with the ASG-EUPOS national reference network. Control points were measured 4 times (30 epochs each measurement). In accordance with (Regulation, 2020), the results were averaged, and a control measurement was also made at the state geodetic control points network, just before starting the measurement, and the legally permissible deviations of the X and Y coordinates were obtained. During tachymetric surveys of building corners, a multi-point connection was made at each total station point (two points of the established control points network). The surveys covered 370 building corners. The measurements of the building's corners (sample of 104 corners covering the test object area evenly) were performed on the images using multiple space intersection in Agisoft Metashape software. Additionally, from the images, a dense point cloud was generated, and measurements of the building corners were performed on the dense point cloud using Terrasolid software.

Evaluation of UAV data in the context of the obtained accuracies

The Regulation of the Minister of Development of August 18, 2020 on technical standards for performing geodetic situational and height surveys and the development and transfer of the results of these surveys to the state geodetic and cartographic resource defines as geodetic situational survey - a set of technical activities consisting in particular in determining the location of terrain details in the state rectangular plane coordinate system and obtaining their basic attributes (§ 2).

Paragraph 3.1 of the Regulation (2020) states that geodetic site and height surveys are performed using methods, techniques, and technologies ensuring the accuracy of the location of field detail points and the fulfillment of the conditions for performing surveys specified in § 16 and § 20, taking into account the principles specified in § 18. Therefore, the regulation does not contain a closed catalog of methods, techniques, and technologies, but rather allows for freedom provided that certain accuracy criteria are met, and § 3.2 states that the selection of the methods, techniques, and technologies used, meeting the conditions for performing surveys and ensuring the required accuracy, rests with the licensed surveyor. § 5. 1. Imposes the condition that geodetic situational and height surveys are performed with reference to the horizontal and height points of the geodetic network.

The regulation in § 6 distinguishes three groups of field details. This division was made to ensure the required accuracy in determining the location of field detail points in the National Flat Rectangular Coordinate System (NFRCS) 2000. The so-called Group I includes field details that are clearly identifiable in the field, maintaining long-term shape and location, in particular: boundary marks and points, buildings, and above-ground construction facilities and construction equipment, including above-ground elements of the utility network;

Paragraph 16 specifies that the geodetic situational survey is performed in a way that ensures the determination of the location of the terrain detail in relation to the points of the horizontal geodetic or control point network, with an accuracy of not less than 0.10 m, in the case of field details included in Group. Paragraph 10.2. It also stipulates that the average error in the position of surveyed points in the horizontal control network cannot exceed 0.10 m in relation to the points in the horizontal geodetic control network.

The Regulation of the Minister of Development, Labor and Technology of July 6, 2021 on geodetic, gravimetric and magnetic networks (Regulation, 2021b), states that the fundamental class of the basic horizontal state geodetic network consists of points included in the state reference stations network of the ASG-EUPOS positioning system, the average horizontal position error of which does not exceed 0.01 m

Therefore, measurements carried out using GNSS technology using the state reference stations network of the ASG-EUPOS positioning system, according to the Head Office of Geodesy and Cartography (GNSS kinematic surveys within RTK/RTN mode using corrections from the ASG-EUPOS network), provide data with a declared accuracy of the horizontal component of 0.03 m.

The horizontal state geodetic network consists of traditional marked-in-the-field points: points previously included in this kind of network, as well as new points whose average position error relative to the tie points after alignment is not greater than 0.07 m (Regulation, 2021b).

The average error in the position of surveyed points in the horizontal control point network cannot be greater than 0.10 m in relation to the points in the state horizontal geodetic network. Geodetic situational survey is performed in a way that ensures the determination of the location of the field detail in relation to the points of the horizontal state or control points network, with an accuracy of not less than: 1) 0.10 m - in the case of field details of group I (Regulation, 2020).

Therefore, a classic measurement using the points of an established control point network (establishing this control network using new points in the geodetic control network is the classic method) will provide results with a maximum average error related to the fundamental basic control network at the level of 0.16 m.

$$m_{PP \text{ traditional control point network + tachymetry survey}} = \sqrt{(0{,}01^2 + 0{,}07^2 + 0{,}10^2 + 0{,}10^2)} = 0{,}16\ [m]$$

For the currently performed surveys of group I of field details, surveys with lower accuracy results are accepted into the state geodetic and cartographic resources.

For control point networks established using GNSS-RTN technology and tachymetric surveys based on them, this result will be as follows.

$$m_{PP \text{ GNSS-RTN control point network + tachymetry survey}} = \sqrt{(0{,}01^2 + 0{,}03^2 + 0{,}10^2)} = 0{,}10m$$

0.01 – position error of ASG-EUPOS reference stations

0.03 – accuracy of the control point network established using the GNSS-RTN method (according to the regulations, it is equal to the accuracy of the ASG-EUPOS positioning service)

0.10 – accuracy of the survey of the details included in I group

To establish a control criterion for measurements using UAVs equipped with GNSS modules and utilizing the ASG-EUPOS network, it should be assumed that the measurements should be within a range of up to 0.10 m. The GNSS module responsible for orienting the camera position in real time performs a somewhat similar task of establishing a control point (0.03 m component in the formula). The measurement itself, using oriented images, must meet the surveying accuracy criteria of the first group of field details (0.10 m component in the formula).

Analysis of the measurement results obtained at the Chrośla cadastral district

370 points were acquired in the Chrośla cadastral district through direct surveys in the field using GNSS-RTN/Tachymetry. Then, for 104 points located in different parts of the test area, measurements were conducted on photogrammetric products, specifically space intersection in images and dense point cloud, using data obtained with the DJI Mavic 3 Enterprise and DJI Zenmuse P1 camera.

In relation to the DJI Mavic 3E, the average difference between the coordinates of building corners obtained using the GNSS-RTN/Tachymetry with the results from space intersection was 0.047 m, and the difference between the coordinates of the building corners obtained in the GNSS-RTN/Tachymetry with the results from point cloud measurements was 0.069 m. The results of differences in building corners coordinates obtained using GNSS-RTN/Tachymetry and from the DJI Mavic 3E UAV, broken down into intervals of differences in building corner coordinates, are presented in Table 4.

Table 4. Differences in the building's corners coordinates obtained using GNSS-RTN/Tachymetry and DJI Mavic 3

Differences in the building's corners coordinates obtained using GNSS-RTN/Tachymetry and from the DJI Mavic 3						
Range of differences in the building's corners coordinates [meters]	**The number of points from a given difference range GNSS-RTN/Tachymetry - space intersection**	**%**	**The number of points from a given difference range GNSS-RTN/Tachymetry – point cloud**	**%**	**The number of points from a given difference range space intersection - point cloud**	**%**
0,000-0,050	67 points	64 %	39 points	38 %	79	76 %
0,051-0,100	31 points	30 %	40 points	38 %	20	19 %
0,101-0,160	6 points	6 %	25 points	24 %	5	5 %
Over 0,161	0 points	0 %	0 points	0 %	0	0 %
Average error	0.047 m		0.069 m		0.038 m	
Max error	0.124 m		0.153 m		0.131 m	

Source: Own study

In relation to the DJI Matrice 300 RTK equipped with Zenmuse P1 camera, the average difference in the coordinates of the building corners obtained using the GNSS-RTN/Tachymetry with the results from space intersection was 0.043 m, and the difference in the coordinates of the building corners measured using the GNSS-RTN/Tachymetry surveys and based on image point cloud was 0.050 m. The results of differences in building corners coordinates obtained using GNSS-RTN/Tachymetry and the DJI Zenmuse P1 camera, broken down into intervals of differences in building corner coordinates, are presented in Table 5.

Table 5. Differences in the building's corners coordinates obtained using GNSS-RTN/Tachymetry and a DJI Matrice 300 RTK UAV equipped with Zenmuse P1 camera

Differences in the building's corners coordinates obtained using GNSS-RTN/Tachymetry and from the DJI Matrice 300 RTK UAV equipped with Zenmuse P1 camera						
Range of differences in the building's corners coordinates [meters]	**The number of points from a given difference range GNSS-RTN/Tachymetry - space intersection**	**%**	**The number of points from a given difference range GNSS-RTN/Tachymetry – point cloud**	**%**	**The number of points from a given difference range space intersection - point cloud**	**%**
0,000-0,050	74 points	71 %	64 points	62 %	97 points	93 %
0,051-0,100	21 points	20 %	26 points	25 %	6 points	6 %
0,101-0,160	9 points	9 %	14 points	13 %	1 points	1 %
Over 0,161	0 points	0 %	0 points	0 %	0 points	0 %
Average error	0.043 m		0.050 m		0.020 m	
Max error	0.132 m		0.148 m		0.119 m	

Source: Own study

With regard to the Zenmuse P1 camera mounted on DJI Matrice 300 RTK UAV, analyzing the achieved results, it can be concluded that the data from the Zenmuse P1 camera provide consistent photogrammetric products, i.e. the correspondence between the coordinates of control points obtained from space intersection and those obtained from the created point cloud is on average 0.020 m, which is a result basically close to the resolution of the images (GSD = 1.5 cm).

This, in turn, gives rise to the conclusion that using selected cameras and flight parameters, there is no need to measure building corners using the space intersection method, and it is enough to generate a point cloud based on which building corners measurement is basically a single action and relatively simpler, because there is no need to identify a given corner on many images clearly.

In the case of space intersection, every point was measured on average over 30 images. Due to the large number of supernumerary observations, such a number of measurements gave greater "confidence", which was finally confirmed in the further stage of comparison of the point coordinates with data from field surveys (GNSS-RTN/Total station). In fact, most of the points measured on the point cloud met the more stringent criterion of measurement difference at a level not exceeding 0.10 m. For 14 points exceeding differences of 0.10 m, these differences were: 0.103 m; 0.104 m; 0.105 m, 0.106 m, 0.106 m, 0.106 m, 0.109 m, 0.114 m, 0.115 m, 0.118 m, 0.131 m, 0.131 m, 0.134 m, 0.148 m, so they did not constitute values that went very far beyond this range.

Regarding space intersection, most points obtained by this method met the more stringent criterion of measurement difference at a level not exceeding 0.10 m. For 9 points exceeding differences of 0.10 m, these differences were: 0.101 m, 0.104 m, 0.104 m, 0.108 m, 0.108 m, 0.116 m, 0.118 m, 0.127 m, 0.132 m.

Analyzing the data acquired with the DJI Mavic 3, it can be concluded that the images allow for the generation of less coherent photogrammetric products than was the case with the Zenmuse P1 camera. The agreement between the coordinates of building vertices obtained from space intersection and those measured on the point cloud is on average 0.038 m. In the case of the DJI Zenmuse P1 camera, 93% of the points showed differences of no more than 0.05 m. In the case of the DJI Mavic 3, this percentage is smaller but still good, amounting to 76%.

In the case of DJI Mavic 3 images, a smaller percentage of points obtained from the point cloud met the more stringent criterion of measurement difference at a level not exceeding 0.10 m. This level was exceeded by 25 points (compared to 14 points for the Zenmuse P1 camera), i.e., almost a quarter of the total number of points (24%). For these 25 points exceeding differences of 0.10 m - these differences were: 0.102 m, 0.102 m, 0.103 m, 0.105 m, 0.105 m, 0.109 m, 0.111 m, 0.113 m, 0.115 m, 0.118 m, 0.119 m, 0.120 m, 0.122 m, 0.126 m, 0.132 m, 0.133 m, 0.137 m, 0.138 m, 0.140 m, 0.140 m, 0.141 m, 0.142 m, 0.143 m, 0.150 m, 0.153 m.

With regard to space intersection, most of the points obtained by this method met the more stringent criterion of measurement difference at a level not exceeding 0.10 m. For 6 points exceeding differences of 0.10 m, these differences were: 0.103 m, 0.104 m, 0.105 m, 0.107 m, 0.119 m, 0.124 m, so they did not constitute values that exceeded this range. In the case of space intersection, each point was measured on an average of 32 photos. It can therefore be concluded that this set can be used to obtain data based on space intersection successfully, and in relation to the point cloud, this method carries a certain risk of providing results that do not meet the accuracy criteria.

Does this provide a basis for the following statement: "For the DJI Mavic 3 with the flight parameters selected as in the experiment, there is no need to acquire data on points (building corners) using the space intersection method, and it is enough to generate a point cloud, as in the case of the DJI Zenmuse P1 camera?

The expected measurement accuracy for the field details is 10 cm, which is defined as an average error of 1 sigma. The results of measurements made using the GNSS-RTN/Total station were accepted as reference, i.e., they were treated as true values. For a sample of 104 corners covering the test object area evenly, the average errors for measurements in photos (indentation): 4.3 cm for P1 and 4.7 cm for Mavic 3, and 5.0 cm and 6.9 cm, respectively, for point cloud measurements. At the same time, the maximum single-point measurement errors did not exceed or were close to three times the average error. And the number of measurements exceeding the permissible average error in the worst case (i.e., for measurements on a point cloud with Mavic 3) was 24%. Therefore, it should be stated that all four measurement series performed meet the expectations (accuracy criteria).

Table 6 presents the differences in building corner coordinates obtained from the DJI Mavic 3 UAV and the Zenmuse P1 camera, categorized by ranges of differences in building corner coordinates.

Table 6. Differences in the building's corners coordinates obtained from the DJI Mavic 3 UAV and the Zenmuse P1 camera

Difference in the buildings' corners coordinates obtained from the DJI Mavic 3 UAV and the Zenmuse P1 camera				
Range of differences in the building's corners coordinates [meters]	**The number of points from a given difference range space intersection**	**%**	**The number of points from a given difference range Point cloud**	**%**
0,000-0,050	90 points	86 %	54 points	52 %
0,051-0,070	10 points	10 %	18 points	17 %
0,071-0,100	4 points	4 %	19 points	18 %
Over 0,100	0 points	0 %	13 points	13 %
Average error	0.034 m		0.057 m	
Max error	0.099 m		0.165 m	

Source: Own study

Based on Table 6, it can be seen that the differences in the coordinates of the building's corners measured from aerial image photos taken with the DJI Mavic 3 and the Zenmuse P1 camera are within 86% of the range from 0 to 5 cm, indicating high consistency in the measurements. Larger difference values occur in the case of building corner coordinates obtained based on measurements from a point cloud generated from images. This may be primarily due to the spatial resolution of the images (GSD). Images from the DJI Mavic 3 had a GSD of 2.85 cm, and DJI Zenmuse P1 - 1.5 cm, so the difference is almost twice. In addition, the DJI Zenmuse P1 camera is a higher-quality camera with a better sensor than the camera in the DJI Mavic 3, so the products (including the point cloud) from the P1 camera will also have higher accuracy. Due to the resolution and quality of the cameras, there are differences in the quality of the point clouds; hence, the measurements made on the point cloud may ultimately be less accurate than those in the images. In the case of the DJI Mavic 3, with such selected parameters and the resulting GSD, it is more accurate to perform the measurement in the images.

Fig. 2 Visualization of differences between the terrain measurements of building corners in comparison to measurements on the point cloud and on the images
Source: Own study

A similar conclusion can be drawn from Fig. 2, where the largest errors are evident in the measurements derived from the point cloud of DJI Mavic 3 images. Additionally, in Fig. 2, some trends can be observed, namely that the differences between the reference measurements are the highest in the south-east part of the test area, regardless of the dataset. Additionally, for the DJI Mavic 3 dataset, the errors for the north-east part of the area are also significantly bigger. The image position error was similar within the whole block, so the trend in error distribution should not be a result of the image adjustment. However, the accuracy of terrain measurements, or also the building properties, such as the contrast between the wall corner and surrounding color, can influence identification possibilities, which also affect the automatic generation of point clouds and the quality of point clouds in these areas.

Fig. 3 Example of building corners that are difficult to identify
Source: Own study

The other aspect is obscuring the building corners by neighboring objects, such as trees, adjacent fences, and close buildings (Fig. 4). This makes it very limited or even impossible to measure some building corners in the images and, consequently, in the photogrammetric products. The completeness, for instance, the percentage of visible building corners, varies depending on the analyzed area. However, if the building corner is obscured by an object, it can also be limited to measuring it in the field using surveying methods, such as tachymetry.

Fig. 4 Examples of a building corner that was not visible in the image because of the vegetation or neighboring objects
Source: Own study

Another factor that can affect measurement accuracy is the quality of the point cloud. The results presented in Tables 4 and 5 suggest that the point cloud from the DJI Mavic 3 is characterized by lower quality. This can also be seen in Fig. 5, which presents horizontal sections through buildings on the dense point cloud generated from P1 and DJI Mavic 3 Enterprise images. Looking at Fig. 5, the differences in noise close to the walls for the Mavic 3 can be seen, which is a noticeable difference, considering that the horizontal sections were generated at the same height as the wall. In the red rectangle, the linearity of the wall is visible in the P1 dense point cloud. In contrast, the points in the point cloud from Mavic images are not regularly distributed in a line, indicating some misplacements.

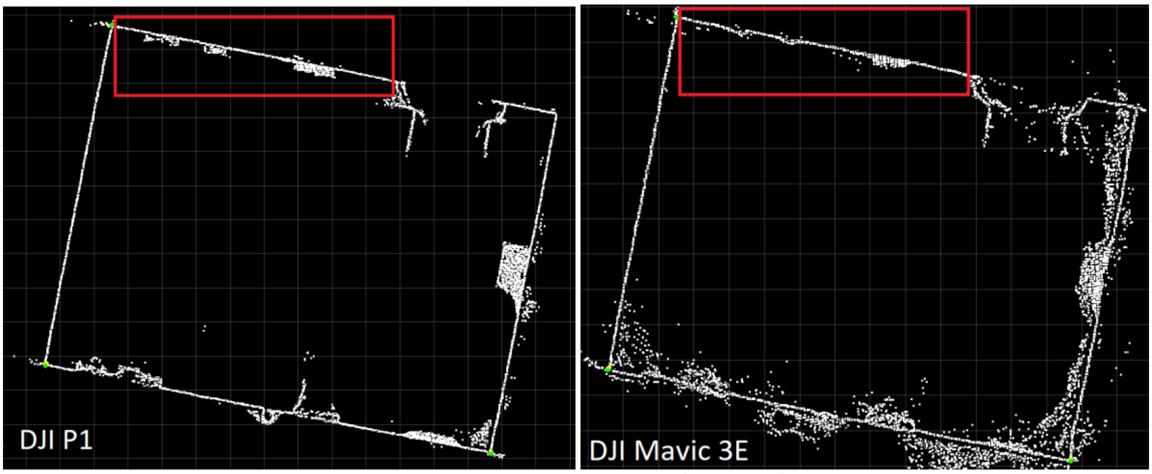

Fig. 5 Horizontal sections through buildings on the dense point cloud generated from P1 (left) and DJI Mavic 3 Enterprise (right) images
Source: Own study

Discussion

UAV images are widely used in many applications, including real estate cadastre, primarily due to their price, automation level, and hardware availability. Thus, this topic is discussed in the literature, and some research results are described. The authors propose the use of UAV technology in land consolidation works (Taszakowski J. et al., 2022; Doroż A. et al., 2023) to verify selected elements of the Polish base map (Brach M., Gąsior J, 2022), and also in works related to complex updating of the cadastral database (Bożek P. et al., 2023). The use of data obtained through measurements using UAVs is also becoming increasingly common in updating geodetic databases in Poland (Bożek P. et al., 2023) and for assessing land boundary accuracy (Ożóg K., 2020).

Many published research works were conducted in small areas, including single or multiple objects (Zrinjski et al., 2019; Manyoky et al., 2012; Mantey & Tagoe, 2019). Šafár et al. (2021) researched a larger area and also focused on the completeness of the identification possibilities. For one test area, 63% of the 1,140 points measured using the traditional geodetic method could be identified in the point cloud. 80 % of the identified points met the accuracy requirement of 0.14m.

In already published articles, in most cases nadir images and nadir orthophotomaps were used (Kędzierski et al., 2015; Karabin et al., 2021; Plichta et al., 2017). On such an orthophotomap, it was difficult to identify building corners; thus, in Karabin et al. (2021), a point cloud was generated from the images acquired with high overlap. In the case of 78 points out of a total of 92 points (i.e., 85%), the differences obtained were: from 0.00 to 0.16 m, with an average error of $m_X = 0.07$ m and $m_Y = 0.09$ m.

Unlike most of the published research, nadir and oblique images were used in this article. 104 building corners were measured within an area of approximately 20 ha, which is a relatively large test area, considering nadir and oblique image acquisition using two different UAVs. A similar comparison, also using two different UAV cameras, was conducted by Soczek et al. (2024), which included oblique images as well.

The differences between our research are primarily in the UAVs used and their equipment. Additionally, our article presents measurements conducted on UAV oblique images and point clouds generated based on these images, in contrast to the mesh model used by Soczek et al. (2024). The mean error for building corners measured on the mesh model from UAV images was 0,121 m and 0,022 m, depending on the used camera. In our experiment, the mean error for image measurement using the DJI P1 camera was 0.043 m, for point cloud: 0.050m, and for the DJI Mavic 3: 0.047 m and 0.069m, respectively. Thus, the results are slightly worse compared to those obtained with the better camera used by Soczek et al. (2024). However, considering the camera quality and permissible error specified in the regulation, the results presented in this article are still sufficient. In Libera et al. (2024), the average error was 0.031m, which is comparable to our results.

Conclusions

General conclusions can be drawn from the presented research regarding the feasibility of using modern UAV technology for real estate cadastre measurements. Firstly, the experiments conducted clearly show that both types of survey-grade UAVs made by the leading manufacturer, when used in reasonable operational conditions (flight height 90 m AGL and "smart oblique" data collection), are able to provide data of sufficient quality to be used for building measurements in cadastre applications. Thanks to this technology, a significant part of surveying work is transferred from the field to the office. The obtained products provide the possibility of a reduction of the time needed for field visits by employees responsible for the cadastre (district office) in case of administrative proceedings or in the case of ordinary customer visits to the cadastral office (explaining matters to customers based on photogrammetric material).

Data from the UAV are enough to identify changes in real estate cadastre data (regarding building outlines). There is, therefore, a direct possibility of applying Art. 22 of the Polish Geodetic and Cartographic Law (Act, 1989), which states that: "If obtaining the data necessary to update cadastral database records is not possible in any other way, the head of a district may, by way of an administrative decision, impose on the owner of the cadastral parcel the obligation to prepare geodetic documentation necessary for the update cadastral database, if it is determined that the actual status of the property is different than that disclosed in this database".

Based on the research work carried out, the following conclusions can be drawn regarding the accuracy of measurements obtained using UAV technology in the context of obtaining geometric data (building corners) to update the real estate cadastre. Undoubtedly, both types of evaluated measurement methods (space intersection and point cloud section) for both drones meet the accuracy requirements currently required by law (RMSE < 10 cm). There is a significant discrepancy in the measurement results between the point cloud generated from data acquired by the DJI Matrice 300 RTK UAV equipped with the Zenmuse P1 camera and the DJI Mavic 3 Enterprise, favoring the DJI Matrice 300 RTK UAV. This can be attributed to the size of the GSD, as well as the camera's quality and sensor pixel size. This affects the density and noise in the point cloud; therefore, due to these two features, the measurements performed on the point cloud are significantly less accurate.

References

Bożek P., Świątek Ł., Doroż A., Taszakowski J., “Wykorzystanie danych z bezzałogowych statków powietrznych do aktualizacji i modernizacji geodezyjnych baz danych” (“Using data from unmanned aerial vehicles to update and modernize geodetic databases”), Przegląd Geodezyjny, no. 11, pp.26-30, 2023, DOI: 10.15199/50.2023.11.2.

Brach M., Gąsior J., “Przydatność niskokosztowego bezzałogowego statku powietrznego do weryfikacji wybranych elementów mapy zasadniczej” (“Usage of the low cost unmanned aerial vehicle in the master map verification process for selected classes”), Przegląd Geodezyjny, r.94, no. 1, pp. 32-35, 2022, DOI: 10.15199/50.2022.1.4

Doroż A., Bożek P., Maciąg K., Maciąg M., Leń P., “Zastosowanie bezzałogowych statków powietrznych w pozyskiwaniu materiałów fotogrametrycznych na potrzeby realizacji kompleksowych prac scaleniowych“ (“The use of UAV in the acquisition of photogrammetric materials for the implementation of land consolidation”), Przegląd Geodezyjny, r.95, no. 6, pp. 24-27, 2023, DOI: 10.15199/50.2023.06.2.

Karabin M., Bakuła K., Łuczyński R., "Verification of the Geometrical Representation of Buildings in Cadastre Using UAV Photogrammetry", Geomatics and Environmental Engineering, vol. 15, no. 4, pp. 81-99, 2021, DOI: 10.7494/geom.2021.15.4.81.

Kędzierski M., Fryśkowska A., Wierzbicki D., Deliś P., "Cadastral Mapping Based on UAV Imagery", presented at 15th International Scientific and Technical Conference "From imagery to map: digital photogrammetric technologies" 26-29 October 2015, Yucatan, Mexico, 2015.\

Libera D., Wajda J., Soczek M., Leń P. “Wykorzystanie modelu 3D z pięcioobiektywowej kamery ukośnej w pomiarach sytuacyjno-wysokościowych” (“The use of a 3D model from a five-lens oblique camera in situational and height measurements”), Przegląd Geodezyjny, no. 3, pp. 27-31, 2024, DOI: 10.15199/50.2024.3.3 *In-text reference*: (Libera D. et al., 2024)

Mantey S., Tagoe N. D., "Suitability of Unmanned Aerial Vehicles for Cadastral Surveys", Ghana Mining Journal, vol. 19, no. 1, pp. 1 – 8, 2019.

Manyoky M., Theiler P., Steudler D., Eisenbeiss H., "Unmanned aerial vehicle in cadastral applications", International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVIII-1/C22, pp. 57–62, 2011, DOI: https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-57-2011.

Ożóg K., "The use of unmanned aerial vehicles for the assessment of land boundaries accuracy", Journal of Water and Land Development, no. 45 (IV–VI), pp. 94–99, 2020, DOI: 10.24425/jwld.2020.133050.

Plichta A., Wyczałek M., Wyczałek I., “Opracowanie części graficznej ewidencji gruntów i budynków w oparciu o zdjęcia lotnicze z pokładu UAV” (Development of the graphic part of the cadastre based on aerial photos from the UAV), Zeszyty naukowe Uniwersytetu Zielonogórskiego, Zeszyt Naukowy nr 45, Inżynieria środowiska 2017. In-text reference*:* (Plichta A. et al., 2017)

Pyka K., Wiącek P., Guzik M., "Surveying with photogrammetric unmanned aerial vehicle", Archives of Photogrammetry, Cartography and Remote Sensing, vol. 32, 2022, pp. 79-102, DOI: 10.14681/apcrs.2020.0004. *In-text reference*: (Pyka K. et al., 2020)

Šafár V., Potucková M., Karas J., Tlustý J., Štefanová E., Jancovic M., Cígler Žofková D., "The Use of UAV in Cadastral Mapping of the Czech Republic", ISPRS International Journal of Geo-Information, vol. 10, issue 6, art. no. 380, 2021, DOI: 10.3390/ijgi10060380.

Soczek M., Wajda J., Libera D., Leń P. "Analiza jakości danych fotogrametrycznych i teledetekcyjnych z wykorzystaniem BSP" ("Analysis of the quality of photogrammetric and remote sensing data using UAVs"), Przegląd Geodezyjny, no. 4, pp. 27-32, 2024, DOI: 10.15199/50.2024.4.3 *In-text reference*: (Soczek M. et al., 2024)

Taszakowski J., Doroż A., Bożek P., Mulica M., "Ocena wykorzystania bezzałogowych statków powietrznych w pracach scaleniowych" ("Assessment of the use of unmanned aerial vehicles in land consolidation works"), Przegląd Geodezyjny, r.94, no. 10, pp. 20-23, 2022, DOI: 10.15199/50.2022.10.1.

Zrinjski M., Barković D., Tupek A., Kober S., "Accuracy analysis of the applicability of UAVs in cadastral surveys", in Conference Proceedings 7th International Conference Contemporary Achievements in Civil Engineering 2019 / Bešević, Miroslav T. - Subotica: University of Novi Sad – Faculty of Civil Engineering Subotica, 2019, pp. 985-993, DOI: 10.14415/konferencijaGFS2019.091.

Act of May 17, 1989 Geodetic and Cartographic Law. Act. Journal of Laws, 2021, item 1990, Poland. *In-text reference*: (Act, 1989)

Regulation of the Minister of Development of August 18, 2020 on technical standards for performing geodetic surveyings, as well as developing and submitting the results of these surveyings to the state geodetic and cartographic resource. Act. Journal of Laws, 2022, item 1670, Poland. In-text reference*:* (Regulation*,* 2020)

Regulation of the Minister of Development, Labor and Technology of July 27, 2021 on the cadastre. Act. Journal of Laws, 2021, item 1390 (as amended), Poland. *In-text reference*: (Regulation, 2021a)

Regulation of the Minister of Development, Labor and Technology of July 6, 2021 on geodetic, gravimetric and magnetic networks *In-text reference*: (Regulation, 2021b)