ACCURACY EVALUATION OF PRODUCTS BASED ON UAV DATA PROCESSED USING DIFFERENT APPROACHES

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Abstract: *The Unmanned Aerial Vehicle (UAV) is an aircraft designed to operate without a human on board. The main advantages of UAVs in photogrammetry are the possibility to acquire very high resolution imagery, but the most important limitation is represented by the area covered in time unit. The SfM algorithm, coupled with the advancements in UAV photogrammetric processes, have significantly enhanced the efficiency, accuracy, and accessibility of aerial mapping using UAVs. This paper gives an overview of the proper workflow with data acquired with photogrammetric sensor (Aeria X) mounted on an eBee SenseFly UAV and a comparison between the products (dense image matching point cloud, digital surface model, and orthophoto) obtained using the most known software: Pix4D Mapper (developed by the company Pix4D) and Metashape (developed by the company Agisoft LLC). In the study case, GCPs are used in the bundle adjustment, in order to generate better quality products. The quality is evaluated by computing metrics, like root mean square errors, but also in a relative manner by measuring distances between different products with Iterative Closest Point method.*

Keywords: *UAV; sensor; DIM; DSM; quality assessment*

1. Introduction

In 1900s, Julius Neubronner used pigeons for aerial image acquisition over the city of Kronberg. The camera that he developed more than 100 years ago is now displayed at the German Museum of Technology. So, it is considered that the pigeon is the predecessor of the UAVs [1]. In 1979, were performed tests with a radio-controlled, fixed-wing UAS with a length of 3 m, equipped with an optical camera [2].

Nowadays, the UAVs can operate autonomously, using an existing flight plan and the GPS-based navigation, or by remote control, in this case it is required to have skilled pilots.

The UAS (Unmanned Aerial System) is composed of the UAV, the camera/scanner, the on-board Global Positioning System (GPS) and the inertial measurement unit (IMU), the Ground Control Station (GSC), and various sensors such as barometers, sonars.

Based on the drive mechanism, the UAVs can be divided in: multirotor (eg. DJI Phantom 4 RTK), fixed-wing (eg. senseFly eBee X) or a hybrid version [3].

The UAV's are used in many types of applications such as: mapping and surveying [4], agriculture [5], tracking and monitoring geohazards [6], historical heritage documentation [7], security, and rescue operations. About 70% of UAVs available are used by the military sector, 17% by the consumer sector, followed by 13% used by the commercial sector [8]. The drone market has grown a lot in the past years, the largest user in the world is the North America and the market value reached, in 2022, is 26.2 billion USD [9]. The improvements that led to the impressive growth of UAVs usage are the development of high quality sensors, battery life, easier-to-use systems, and the enhancement of the structure-from-motion (SfM) software.

Photogrammetric products can be obtained from cameras mounted on planes, helicopters or UAVs. The main advantages of UAVs are the possibility to acquire very high resolution imagery (1-5 cm) or low-to-the-ground scanning (eg. 1000points/sqm) and the economic aspect, they represent the cheapest solution. The limitations involve extreme weather conditions (including strong winds), the limited battery power (eg. 90 minutes), smaller coverage areas, and the national regulations for flights [10].

In the beginnings, the UAVs were used only for recreational purposes and there were no clear and strict regulations. However, when the UAVs started to be used in other areas of activity and the number of users increased, clear legislation was needed. The rules are applied differently between the amateur, the professional or the commercial use. Some countries have institutions that issue certificates for pilots, register UAV devices, and control the use of UAVs in their airspace [11]. This is also the case of Romania that follows closely the European rules. UAV’s can fly in Romania under European Union Aviation Safety Agency (EASA) drone laws [12]. The Romanian Civil Aviation Authority (RCAA) supervises and implements drone restrictions at national level. For performing photogrammetric flights with a drone in Romania you must register it at the RCAA, you have to be a registered UAV operator, the pilot has to have an EU Licence - Basic Certificate (A1-A3) and the Supplementary Certificate (A2). Before the photogrammetric flight you should get approvals from the Ministry of National Defence and flying permits from the responsible entity (e.g., control tower).

The place of UAVs in the photogrammetric projects is clear (small sized areas) and overlaps with the aerial photogrammetry for medium sized areas [13].

2. Metodology

The typical photogrammetric workflow with sensors mounted on UAVs involves the following steps: flight planning, data acquisition, image processing, photogrammetric reconstruction, digital surface model (DSM) generation, orthophoto generation and quality assessment. Each step in this workflow requires specialized software and expertise in photogrammetry techniques. There are many factors, like weather conditions, equipment calibration, and image quality that can influence the quality of the final output [13]. The methods used for geo-referencing the UAV data are direct and indirect. Direct geo-referencing can be done using the camera position information from the GNSS receiver places on-board the UAV. Indirect geo-referencing involves using the coordinates of specific points on ground known as Ground Control Points (GCPs). The most important requirements of a premarked GCP are the size, visibility, location, distinctiveness, and accuracy of field measurements. There are many studies for UAV projects that evaluate the optimal number of GCPs and the most suitable placement pattern [14]. The Direct Geo-referencing method is faster and more cost-effective, but it yields lower solution quality than the indirect Geo-referencing [15].

Tie point’s extraction uses feature detection algorithms that finds distinctive points or features in each image, like SIFT, SURF, ORB. Images are brought together in a unique geometric coordinate system using Multi-View Stereo (MVS) and Structure from Motion (SfM) algorithms [16]. The SFM algorithm detects common feature points in multiple images and uses them to reconstruct the movement of those points throughout the image sequence [17].

The final part of the bundle adjustment is the parameters fine-tuning and the minimization of the differences between the observed image points and their corresponding points predicted by the geometric model [18]. The dense image matching (DIM) step is the process of establishing correspondences between points or pixels in images. The common technique for DIM generation is the Semi-Global Matching (SGM) algorithm [19].

Interpolation methods for DSM generation involves techniques to estimate values between known data points. Several methods are commonly used: Delaunay triangulation, inverse distance weighting, kriging, nearest neighbor, bilinear interpolation, cubic interpolation. In drone software development, the choice of interpolation method depends on many factors and the selection should be based on the specific needs of the project [20]. Using the DSM, a true-orthophoto is generated, by combining images captured from different points of view so that areas occluded in some images can be filled by other views [21].

3. Results and discussion

The study area was chosen in the extravillan area of Buzoeni village (Figure 1). For establishing the study area, the terrain configuration, the maximum allowed flight altitude for the OPEN category (120m), the position of the high voltage power lines, and the restricted areas were considered.

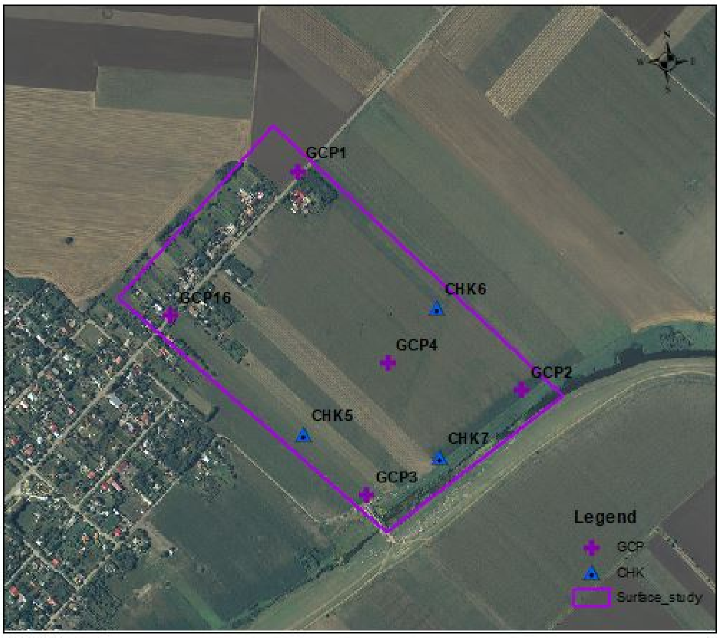

Figure 1. Study case area

Prior to the data acquisition, the flight plan was done using eMotion software (Figure 2) and the parameters shown in Table 1.

Input parameters	
Photogrammetric sensor	Aeria X
Image spatial resolution	2.5 cm/px
Image overlaps	60% / 60%
Test area	24.9 ha
Flight altitude	118 m

Table 1 Basic flight parameters

Figure 2. Flight plan and parameters used

Before the flight, the GCPs and CHKs were premarked in the field using plastic tiles (40cmx40cm), as shown in Figure 3. The points were measured using GNSS static measurements for 2 hours. The number of GCPs used was 5 and their position was one in each corner and one in the middle of the block.

The flight was done in the OPEN category, in 30.10.2023, when the sun angle had values bigger than 30°. For the 13 flight lines, 162 images with 2.5 cm/pixel spatial resolution were acquired.

Figure 3. Premarking of GCPs

A. Products Generation

Within this study, the focus was on using two approaches implemented in the most used software packages for UAV data processing: Pix4Dmapper and AgiSoft Metashape. The workflow is similar for both software: image alignment (Figure 4), construction of point clouds and 3D mesh, generation of DSM and orthophotos. Additionally, the processing in Metashape software enables the user to set up the calibrated parameters of the camera.

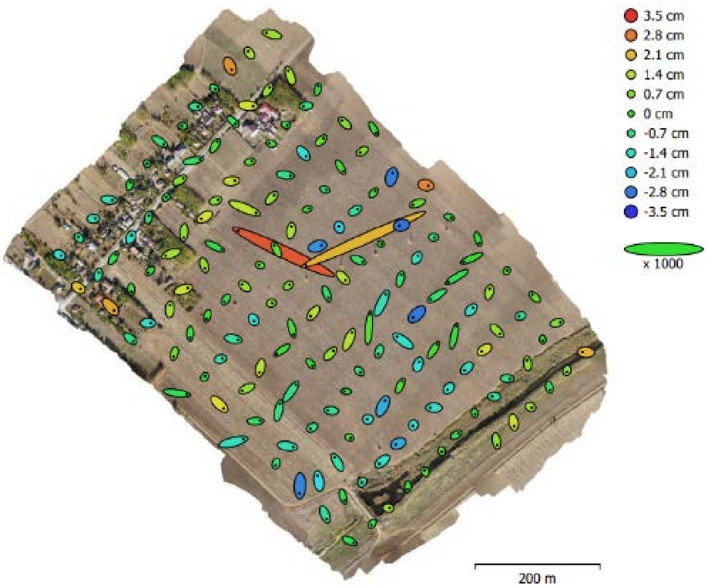

Figure 4. Camera locations and error estimates in Metashape (Z error is represented by ellipse color and X,Y errors are represented by ellipse shape)

The products generated in the two software are DIM, DSM and true-ortohophoto (Figure 5). Some important metrics of the block and of the products are displayed in Table 2.

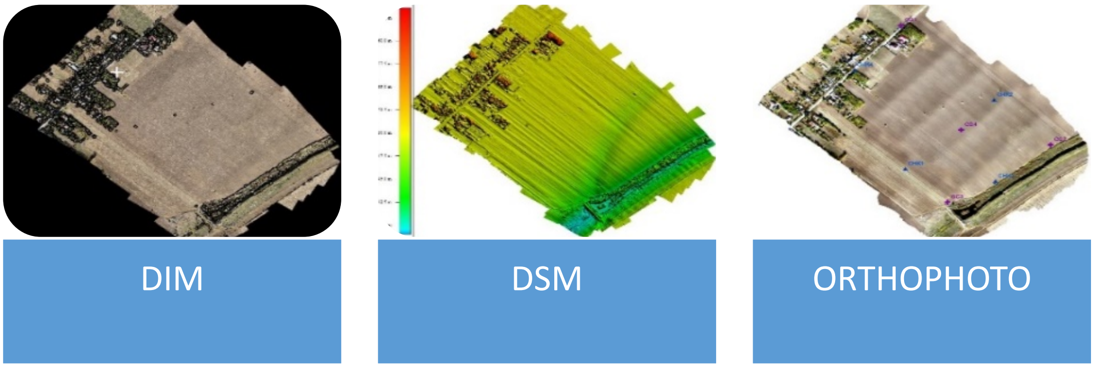

Figure 5. Products generated in Metashape software

		PIX4D	METASHAPE
Image acquisition	Area covered (km2)	0.457	0.481
	Average GSD	2.52	2.49
Bundle Block Adjustment	Mean Reprojection Error (pixels)	0.146	0.155
DIM	Number of points	158181493	47811613
	Average density	796 (points per m^3)	100 (points per m^2)
DSM	Resolution (cm)	2.52	9.98
Ortohophoto	Resolution (cm)	2.52	2.49

Table 2. Processing and products information

B. Quality evaluation

By comparing the number of points in the DIM files (Table 2), both in Pix4D and in Metashape, it can be stated that the DIM generated by Pix4D software is denser. After comparing the two datasets using the Iterative Closest Point method (ICP), the DIM from Pix4D reveals many gaps in the building and vegetated areas. These errors led to the big differences in Figure 6.

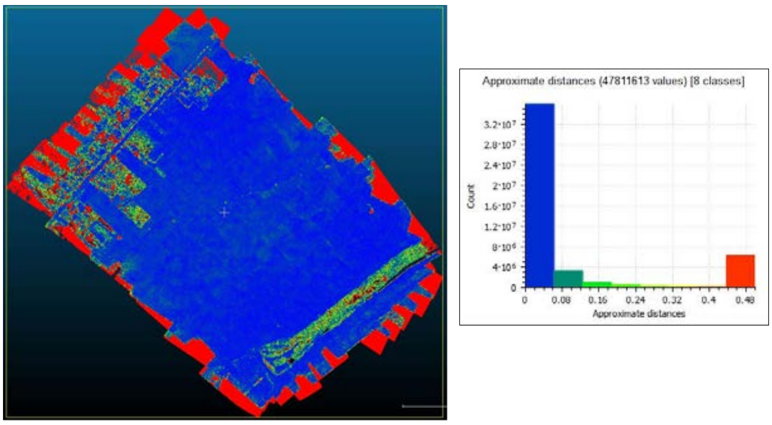

Figure 6. DIMs comparison

In order to illustrate the differences in the DSMs obtained, several elevation profiles were generated in areas like: roofs, water, and roads. One example is displayed in Figure 7.

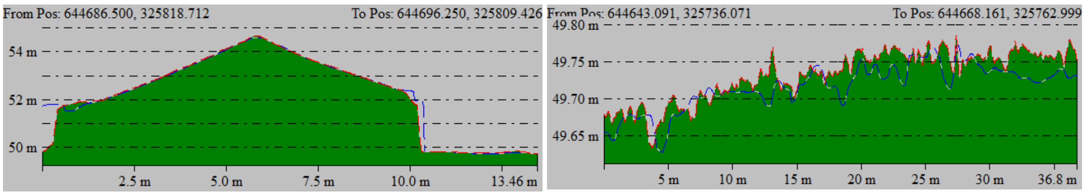

Figure 7. DSM profiles on roofs, roads (red - Metashape, blue - Pix4D)

For the quality evaluation of the DSMs were used 27 points, three of them (red in Figure 8) were measured in the field with static GNSS measurements and the other 24 (green in Figure 8) were extracted from a precise DIM. The results are displayed in Table 3.The DIM and MDS used as ground truth in the following checks are products generated in the on-going National project for high resolution image acquisition in Romania. The main project activities are acquiring aerial images with high spatial resolutions, performing bundle block adjustment and dense image matching, generating the digital surface models and the true-orthophotos. The quality control checks are done by experts from the National Center of Cartography, who is also the Beneficiary. The DSM, derived from images acquired over the city of Lehliu-Gară (that covers the area of Buzoeni too) with UltraCam Lp camera at a spatial resolution of 15cm, has a resolution of 50cm and a computed altimetric RMSE of 8.3cm.

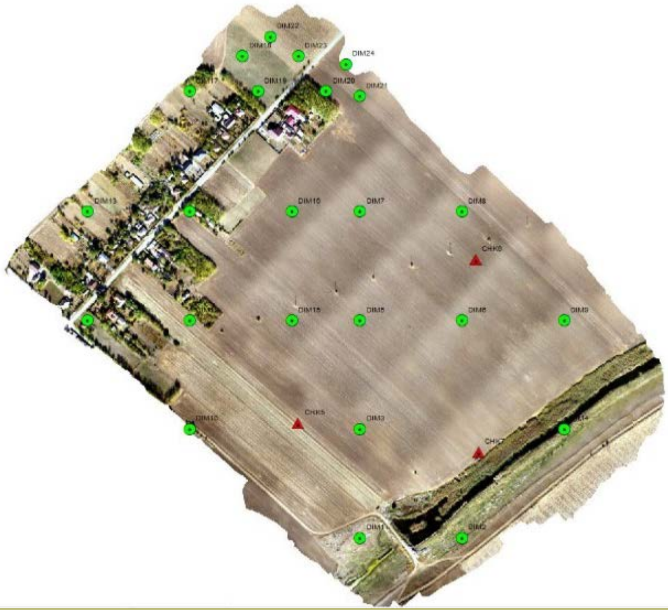

Figure 8. Points used for quality checks in DSM

	RMSE CHK (m)	RMSE DIM points (m)
Pix4D	0.111	0.198
Metashape	0.117	0.190

Table 3. RMSE values for DSM

A comparison between the DSM considered ground truth and the products generated in Pix4D and Metashape was performed by generating difference raster using the resolution of 10 cm. The differences shown in Figure 9 are due to the process of generating the DIM and DSM, but also due to the different period in which the images were acquired (spring and autumn).

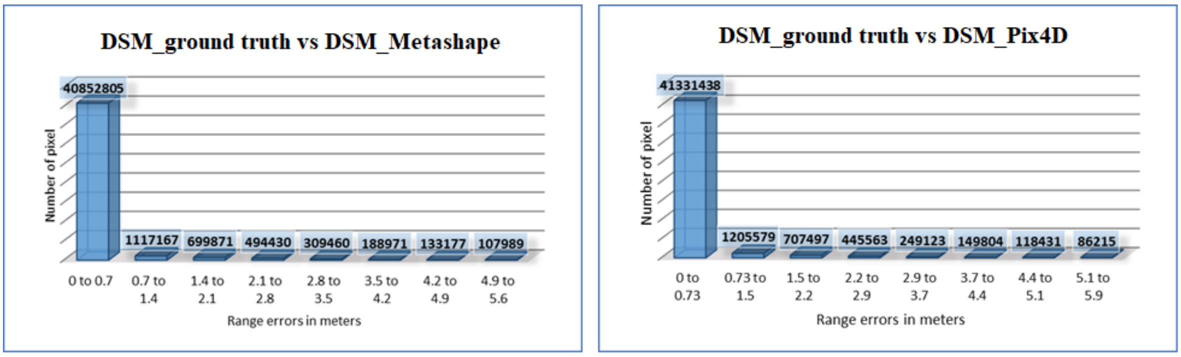

Figure 9. DSM differences between products and the ground truth

For better understanding the differences between the 2 products, areas with different characteristics were selected and the values of H coordinate (eg. Figure 10) was extracted from the DSM and was compared with the ground truth (Figure 11). In Table 4 differences of 3 to 5 cm are shown, putting the DSM generated in Metahape closer to the reality in the field.

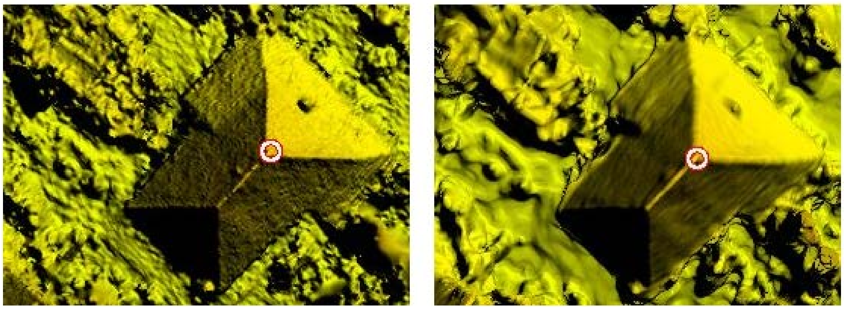

Figure 10. DSM differences between Metashape and Pix4D
(measurement of the roof point in Table 4)

Object	H (m)		H (m) DSM-ground truth	ΔH (m)	
	Pix4D DSM	**Metashape DSM**		**Pix4D DSM**	**Metashape DSM**
roof	54.49	54.43	54.16	0.33	**0.27**
road	49.76	49.73	49.41	0.35	**0.32**
water area	40.71	40.73	40.9	-0.19	**-0.17**
bare earth	49.4	49.42	49.27	0.13	**0.15**

Table 4. Differences in height from the DSM

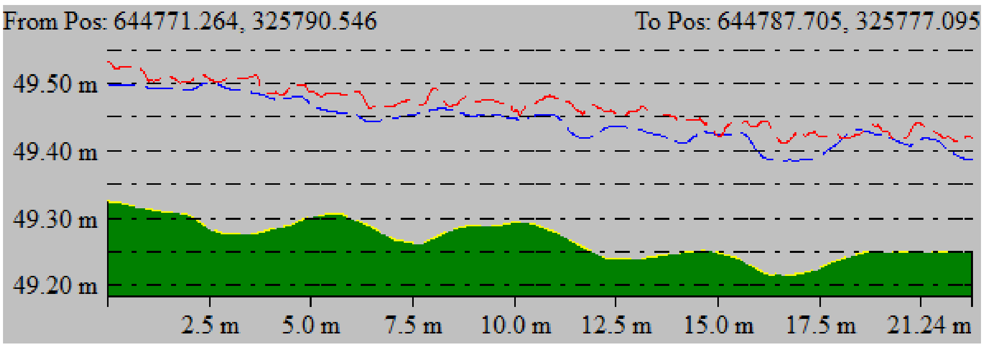

Figure 11. DSM differences (green - ground truth, red - Metashape, blue - Pix4D)

For the quality evaluation of orthophotos 8 points were used and the values of planimetric root mean square errors were approximately 3 cm in both cases (Figure 12).

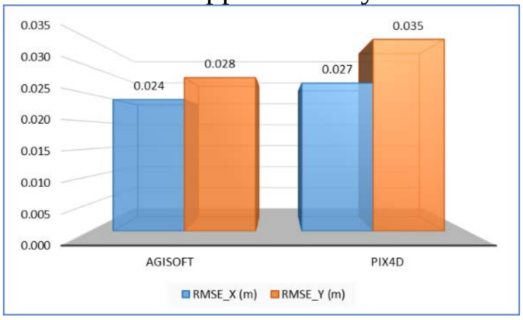

Figure 12. RMSE in meters of orthophotos in X and Y coordinates

For a visual inspection, Figure 13 displays some detailed views in the orthophotos. The product from Metashape renders better the fances, the building roofs and keeps the real position of trees. Most of the artifacts generated by Pix4D are due to vegetation and other objects above ground.

Figure 13. Examples of artifacts in orthophotos - detailed view
(right image - Metashape, left image - Pix4D)

4. Conclusions

The study conducted in the extravillan area of Buzoeni village aimed to assess the performance of two software packages for processing UAV data, Pix4Dmapper and AgiSoft Metashape. Several key steps were taken to ensure accurate data acquisition and processing, including meticulous flight planning, ground control points placement, and image acquisition under favourable conditions.

Due to the different error sources in the matching process and repetitive texture in some areas with big building and high vegetation, there are some gaps in the DIM generated in Pix4D. So, it can be stated that Agisoft offers better performance in capturing details such as building roofs and vegetation, resulting in a DIM closer to the reality in the field.

Furthermore, the evaluation of DSMs and orthophotos highlighted the superiority of AgiSoft in accurately representing terrain features and minimizing artifacts, particularly in areas with many above-ground objects. The elevation profiles and differences raster's analysis confirmed the consistency of Agisoft products with ground truth data, underlining its reliability for various applications.

Overall, while both Pix4Dmapper and AgiSoft Metashape offer valuable tools for UAV data processing and geospatial analysis, the choice between them should consider specific project requirements, such as accuracy, density of point clouds, or products specifications.

For UAV photogrammetry, the accuracy of the obtained products can be greatly affected by many variables, such as geo-referencing methods, the number of GCPs, and the type of software used.

5. References

1. *1. Wanger I., Gries B. Julius Neubronner and his flying photographers. n.d. 16 04 2024. <https://tinyurl.com/mv2vf8pw>.*
2. *Przybilla H. J., Ebbinghaus W. W.,. "Bildflug mit ferngelenktem Kleinflugzeug." Vol. 5/47 (1979): 137 - 142.*
3. *Mazur M., Wiśniewski A.,. Clarity from above PwC global report on the commercial applications of drone technology. Polska: Drone Powered Solution, 2016.*
4. *Park S., Choi Y.,. "Applications of Unmanned Aerial Vehicles in Mining from Exploration to Reclamation: A Review. Minerals." Minerals Vol 10 (8) (2020): 663.*
5. *Grenzdörffer G. J., Engel A., Teichert B.,. "The photogrammetric potential of low-cost UAVs in forestry and agriculture." Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci (2008).*
6. *Kovanič I.. Blistan P., Urban R., Štroner M., Blišťanová M., Bartoš K., Pukanská K.,. "Analysis of the Suitability of High-Resolution DEM Obtained Using ALS and UAS (SfM) for the Identification of Changes and Monitoring the Development of Selected Geohazards in the Alpine Environment—A Case Study in High Tatras, Slovakia." Remote Sensing (ISSN 2072-4292) (2020).*
7. *Petráček P., Krátký V.,Saska M.,. "Dronument: System for Reliable Deployment of Micro Aerial Vehicles in Dark Areas of Large Historical Monuments. In IEEE Robotics and Automation Letters." IEEE: Piscataway, NJ, USA, 2020; Volume 5 (2020): 2078–2085.*
8. *Gupta A., Afrin T., Scully E.,Yodo N.,. "Advances of UAVs toward Future Transportation: The State-of-the-Art, Challenges, and Opportunities." Future Transp. 1 (2021): 326-350.*
9. *UAV DRONE MARKET. 2023. 16 04 2024. <https://tinyurl.com/yckfy4cd>.*
10. *10. Stöcker C., Bennett R., Nex F., Gerke M., Zevenbergen J.,. "Review of the Current State of UAV Regulations." Remote Sens , 9, (2017): 459.*
11. *Kovanič Ľ., Topitzer B., Peťovský P., Blišťan P., Gergeľová M.B., Blišťanová M.,. "Review of Photogrammetric and Lidar Applications of UAV." Appl. Sci. , 13, (2023): 6732.*
12. *Autoritatea Aeronautică Civilă Română. Civil unmanned aircraft – UAS operations. 12 11 2023. 18 04 2024. <https://www.caa.ro/en/pages/legislatie-drone>.*
13. *Nex F., Remondino F.,. "UAV for 3D mapping applications: a review,." Applied Geomatics Italy (2014).*
14. *Bhatsada A., Wangyao K. "The optimum number and placement pattern of Ground Control Points for mapping in risk areas: a case study of landfill mapping." Fresenius Environmental Bulletin vol.31 (2022): 7888-7901.*
15. *Elkhrachy I. "Accuracy Assessment of Low-Cost Unmanned Aerial Vehicle (UAV) Photogrammetry ." Alexandria Engineering Journal,vol.60 (2021): 5579-5590.*
16. *Pepe M., Alfio V.S., Costantino D.,. "UAV Platforms and the SfM-MVS Approach in the 3D Surveys and Modelling: A Review in the Cultural Heritage Field." Appl. Sci. vol. 12, (2022): 12886.*
17. *Girelli, V.A.Borgatti, L., Dellapasqua, M., Mandanici E., Spreafico M.C.,Tini M.A., Bitelli G.,. "Integration of Geomatics Techniques for Digitizing Highly Relevant Geological and Cultural Heritage Sites: The Case of San Leo (Italy). ." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (2017).*

18. *Giordano S., Le Bris A., Mallet C.,. "Toward automatic georeferencing of Archival Aerial Photogrammetric Surveys." ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-2 (2018).*
19. *Gehrke S., Downey M. , Uebbing R., Welter J., LaRocque W.,. "A MULTI-SENSOR APPROACH TO SEMI-GLOBAL MATCHING." ISPRS (2012).*
20. *Leal-Alves D.C., Weschenfelder J., Albuquerque M.d., et al. "Digital elevation model generation using UAV-SfM photogrammetry techniques to map sea-level rise scenarios at Cassino Beach, Brazil." SN Appl. Sci. 2, 2181 (2020).*
21. *Biason A., Dequal S., Lingua A.,. "A New Procedure for theautomatic production of true orthophotos." International Archivesof Photogrammetry, Remote Sensing and Spatial InformationSciences, Vol. 35 (2003): 538-543.*