Cadastral Survey of a Fishpond Using UAV Photogrammetry

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SUMMARY

The land management is nowadays one of the most important things. A complex and precise tool for the evidence of land use, such as cadastre, is the condition for a functioning land management system. Measurements of the land surveyors are the base of the cadastre. In the present, in Slovakia only “classical” land surveying methods are used for the cadastral surveys, such as GNSS method or polar method. Today we witness an evolution of the cadastral system and its expansion into the third dimension. We are slowly getting to a point where classical surveying methods would be insufficient and modern and smart technologies should be used, which would provide more information. There is also a pressure to get the results effectively, using less time and money. One of the modern and smart technologies which would be suitable for the cadastral survey is the unmanned aerial vehicle (UAV) photogrammetry. The main aim of this paper is to test a cadastral survey of a fishpond situated near Bratislava using UAV photogrammetry. In the first part, the process of taking the photos and their processing using standard Structure-from-Motion method are described. The next part deals with the results. The main product for the purposes of the cadastral survey was an orthomosaic, where the detailed cadastral points were identified, but an experimental technique of the point identification on the 3D model was used as well. The results were verified on a set of check points where positional deviations between the cadastral map and the photogrammetric measurement were calculated and the effectiveness has also been assessed.

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1. INTRODUCTION

A functioning land management system is nowadays one of the most important elements. For this purpose, we need a precise and complex tool for the land use evidence, such as cadastre of real estate. In the Slovak Republic, there are many problems in the cadastre and there is a lot of information of different origin and quality. The cadastral maps represent probably the biggest problem. Many of them are not accurate enough for the current requirements. There is a need for a complex renewal of these maps because only accurate information about the plot boundaries and land use is sufficiently reliable for a successful land management. In Slovakia, mainly "classical" surveying methods are used for the cadastral surveys, such as the polar method, orthogonal method or GNSS method. However, these are gradually becoming insufficient because the cadastral system is slowly evolving into the third dimension and the information provided by these methods is not satisfactory. Also, the new mapping using these methods is advancing very slowly because these methods are very ineffective in some cases. Cadastral surveys require modern and smart technologies, such as photogrammetry.

The aerial photogrammetry in cadastral surveys has been a long-known topic, which is a subject of a number of foreign publications (Weismann, 1971; Williamson, 1983; Demir et al., 2008) as well as some Slovak publications (Horňanský, Ondrejička and Šuppová, 2014). In these cases, it was a "classical" aerial photogrammetry, which is more suitable for the creation of topographic maps than cadastral surveys. However, the photogrammetric method in cadastre is still a relevant topic. Many authors deal with the determination of cadastral boundaries from large scale photogrammetric maps, ortho-rectified images or high-resolution satellite images (Alkan and Solak, 2010; Rao et al., 2014; Ali, Tuladhar and Zevenbergen, 2013). Several articles also examine the automated extraction of plot boundaries from images and its comparison with the manual extraction (Nyandwi, Koeva, Kohli and Bennett, 2019). However, some authors concluded that the photogrammetric method did not meet the requirements for the cadastral purposes. (Benduch and Pęska-Siwik, 2017)

In recent years, there has been a new trend of data obtaining for the cadastral surveys using aerial images made with unmanned aerial vehicles (UAV). This technique is called UAV photogrammetry. The evaluation of effectiveness and precision of this method in the Slovak Republic has not been carried out yet. In the Czech Republic, there was a research examining the possibility of usage of the UAV photogrammetry in the cadastral mapping and the way of the evaluation of precision (Šafář et al., 2015) as well as the evaluation of precision of the UAV photogrammetry in a cadastral survey in a rural area (Housarová, Šedina and Pavelka, 2016). The UAV photogrammetry in cadastral surveys has been a well-known topic also in several other countries. Many articles deal with the determination of cadastral boundaries from the UAV-derived orthoimages (Rijsdijk et al. 2013) and the accuracy of this method has been tested as well (Sung, Lee, 2016). Using stereo mapping mode for the measurement of cadastral plots in the urban area is another possibility for the UAV photogrammetry in cadastral surveys (Chio, Chiang, 2020). Some research studies also investigate the possibility of an automatic boundary extraction from drone images (Fetai et al., 2019; Crommelinck et al., 2018). One of the benefits of the UAV photogrammetry is that it provides not only coordinates of cadastral boundaries, but also many other results, which are applicable in various fields (Manyoky et al., 2011).

There are some efforts nowadays in Slovakia aimed at the renewal of cadastral maps, but the work is proceeding very slowly. This process of a new mapping is immensely time consuming and expensive. If we want a functioning land use evidence on the 21st century level, we need to introduce some new methods of measurement. One of these methods could be the unmanned aerial vehicle (UAV) photogrammetry. The aerial photogrammetry was used in the past for the cadastral surveys, but its precision was not satisfying. That is due to the fact that the aeroplanes were used, and the flying altitude was high. But if an UAV is used, we can fly in a lower altitude and capture more details, which means the precision would be better as well. The UAVs provide 3D information about the surveyed objects and can save time and money significantly because nowadays they are affordable and have cameras of a high quality. This means that if the UAV photogrammetry meets the requirements for the precision, it presents a cheap and fast solution for the cadastral maps renewal.

The main aim of this article is to test the UAV photogrammetry method in a cadastral survey of a fishpond situated near the capital of Bratislava. In the first section, the requirements for the precision of points in the cadastre in Slovakia are described. The next part addresses the process of planning, taking the photos with an UAV and their processing with the Structure-from-Motion (SfM) method. The last part of the paper deals with the description of the obtained results and the assessment of effectiveness of the UAV photogrammetry. These results represent one of the first evaluation reports of this method in cadastral surveys in Slovakia and can be used for a future research.

2. MATERIALS AND METHODS

2.1 Quality of points in cadastral maps

In the cadastre, there is a lot of data of various origin and quality and this quality has to be assessed in some way. According to Decree no. 461/2009 Coll. there is only one parameter for the quality assessment of cadastral maps, which is the quality code of a detailed point “T”. The value of the quality point is given to a point according to its origin and positional accuracy. The characteristic for the positional accuracy is the mean coordinate error m_{xy}, calculated with the formula (1).

$$m_{xy} = \sqrt{0.5\left(m_x^2 + m_y^2\right)}, \qquad (1)$$

where m_x and m_y are mean positional errors in the direction of coordinate axes x and y. Each value of quality code has its own value of mean coordinate error (Decree no. 461/2009 Coll.) (Table 1).

Table 1: Quality code of detailed point (positional accuracy)

"T"	**Mean coordinate error**
1	m_{xy} = 0, 08 m
2	m_{xy} = 0,08 m
3	m_{xy}= 0,14 m
4	m_{xy}= 0,26 m
5	m_{xy} without distinction of accuracy

Detailed points in the map with the quality code value "1" to "4" were determined with numerical measuring methods, which means that the coordinates of the points were recorded. The quality code "1" is used for points which were determined after 2009 using the GNSS-RTK method connected to the SKPOS permanent network. The quality code "2" has the same mean coordinate error as "1", but the difference is that these points were not determined in the field, but they were taken from other documentation. The points with the quality code "3" were determined before 2009 using only terrestrial measurement methods with connection to the existing geodetic control point network. These points are situated mainly in urban areas. The points with the quality code "4" were determined before 2009 using terrestrial methods or the classical aerial photogrammetry and are situated mainly in rural or forest areas, where such a high precision is not necessary. The points with the quality code "5" were determined cartometrically from the scans of old Hungarian cadastral maps, which were transformed into Unified Trigonometric Cadastral Network (UTCN) system. They are without distinction of accuracy, because their accuracy is practically unknown. We presume that it is between 2 and 5 m.

There are several ways to practically assess the quality of a point in the cadastral map during the new measurement. The most common one is a positional assessing. In this way we check if the mean coordinate error m_{xy} does not exceed a criterion u_{xy}. A position of a point is determined and then a positional deviation Δp between the existing point in the map and the point determined by the measurement is calculated using the formula (2).

$$\Delta p = \sqrt{\Delta x^2 + \Delta y^2}. \qquad (2)$$

The positional deviation Δp must not exceed the value Δp_{max}, which is given by the formula (3).

$$\Delta p_{max} = 1.7 u_{xy}, \qquad (3)$$

where u_{xy} is a criterion and its value is a mean coordinate error given by the quality code of the point. This means that the positional deviation Δp must not exceed 0.24 m for the points with the quality code "3" and 0.14 m for the points with the quality code "1". The same practice applies to the newly determined points, but the difference is that the point has to be determined twice with different conditions during the measurement or different methods. This method of precision evaluation is used in this paper, where the cadastral map serves as a reference and the positional deviations Δp between the points in the cadastral map and the points determined by the UAV photogrammetry are calculated and compared with the maximal value.

2.2 Testing area, equipment, and flight planning

For the testing of the UAV photogrammetry in a cadastral survey, it was necessary to choose a testing area. This area is a fishpond on the outskirts of the capital city, Bratislava (Figure 1). It is situated in a typical suburban area.

Fig. 1: Overview of a testing area *(source: Google Maps [09-02-2021])*

The area of this fishpond is approximately 25 000 m^2. In the past, it served mainly for the breeding of fish but also for recreational purposes. There is a big problem with ownership rights and the fishpond is becoming desolate because the owners are not able to reach a deal about the reconstruction. In order to settle the ownership rights a geodetic sketch has to be made. For this documentation it is necessary to perform an updating measurement because the fishpond has changed its shape since the original measurement. The UAV photogrammetry is ideal here because the measurer could stay on the road and they would not get wet and dirty during the measurement.

For the shooting of photos, a DJI Mavic Air 2 drone (Figure 2) was used. This quadrocopter has four rotors, which provides the wind resistance up to 10.5 m/s. Its flight time is up to 34 minutes on one battery, so with three batteries, it can fly up to one and a half hours. With its weight of 570 g it belongs to the C1 category according to the Slovak legislation. The only restriction of this category is that it cannot be flied above the gatherings of people. The flight can be performed without restriction even in urban areas, which is a great advantage for the cadastral mapping. The drone is equipped with a built-in 1/2-inch CMOS sensor, which can be operated in two modes – 12 MP mode and 48 MP mode. The focal length is 24 mm and FOV is 84°. The camera is stabilized with a 3-axis mechanical gimbal. DJI Mavic Air 2 is also equipped with a GPS receiver and an obstacle avoidance system. (Mavic Air 2 User Manual, 2020) Its price is affordable, which makes this drone a suitable option for the cadastral mapping.

Fig. 2: DJI Mavic Air 2 drone *(source: https://www.dji.com/sk/mavic-air-2 [13-02-2021])*

To get the results in the UTCN reference system, a set of ground control points (GCP) had to be determined. GCPs were determined with the GNSS-RTK measuring method, connected to the SKPOS permanent GNSS network. The GNSS receiver used was a Leica GS08. The point quality of this method using the SKPOS network is declared to 2-3 cm. There were eight GCPs determined on the edge of the fishpond (Figure 3). Besides GCPs, there were several other points of cadastral boundaries determined, which serve for the quality verification of the cadastral map. The map serves as a reference for the verification of the UAV photogrammetry method. The GCPs were signalized naturally (e.g. corner of a concrete block, see Figure 4).

Figure 3: GCPs configuration


Figure 4: Naturally signalized GCP

The successful use of the UAV photogrammetry method requires a careful flight planning. Most of the area of the surveyed fishpond is without a problem, so a classical flight pattern with shooting the photos in stripes with camera in nadir direction can be used. To get most of the details, the flight altitude was chosen to be 20 m, which is equal to approximately 0.6 cm GSD. The overlap of images in the stripes was planned to be approximately 80% and the transversal overlap between the stripes approximately 40%. The problem was the southern and western edge of the fishpond, where are very high trees, so the classical flight pattern could not be used here due to the risk of an accident. It was decided to fly along the edge with the camera inclined in 45°-50° angle and to shoot oblique photos with approximately 80% overlap, flying in the same altitude of 20 m. The drone is operated through a DJI Fly application in the smartphone, which does not support flight planning and autonomous flight according to the planned parameters. No flight planning software was used for this flight. In Slovakia, it is also prohibited to fly a drone autonomously according to the legislation and a pilot has to operate the drone manually for the whole flight time. Therefore, it was only up to the pilot to keep the planned flight parameters manually.

2.3 Data processing

The data was processed with a standard Structure-from-Motion practice. The software used was Agisoft Metashape Professional. It is a commercial software which supports the whole processing chain, including calibration of camera, georeferencing and generation of a whole range of results. The camera was not precalibrated and a self-calibration was used. The first step consisted in loading and aligning photos, the result of which was a sparse point cloud. After aligning photos, a georeferencing was made, which consisted of identifying and marking the GCPs on the photos. Then, the optimization of all parameters was carried out, including camera calibration parameters. In this step, a bundle adjustment was performed. The next step focused on a dense cloud generation followed by a 3D mesh generation. With a mesh generated, it is also possible to generate a texture, or a DSM. The main product for the purposes of the cadastral survey is an orthomosaic, which can be generated based on the mesh. (Agisoft Metashape User Manual, 2019) After exporting the orthomosaic in the GeoTIFF or JPG format, it can be opened in a CAD software where it is possible to obtain the coordinates of the detailed points. These coordinates can also be obtained via identifying the points on the several photos in the Metashape software when the software calculates the coordinates according to the orientation parameters.

3. RESULTS AND DISCUSSION

The measurement was performed in the outskirts of Bratislava in the early December 2020. The fishpond was without the water due to winter maintenance, which simplified the whole measurement and the model of the bed of the fishpond could be obtained. The first step consisted in the GNSS-RTK measurement with connection to the SKPOS permanent GNSS network with a Leica GS08 GNSS receiver. The position of eight naturally signalized GCPs and several other check points of the cadastral boundaries was determined. The check points served for the independent quality check of the cadastral map in the measurement area. The positional deviations between the points determined by the GNSS-RTK method and the points in the cadastral map were all less than 0.05 m, which means that the cadastral map can be used as a reference for the precision evaluation of the UAV photogrammetry method. This GNSS measurement took approximately 15 minutes of time and only one person was needed for it.

After the GNSS measurement, the flight with the DJI Mavic Air 2 drone was performed. The flight parameters were planned in advance, but the drone is controlled through the DJI Fly app, which does not have the possibility to fly autonomously according to a flight plan. Due to this fact, and also extreme weather conditions on the day of measurement, with wind gusts up to 100 kph, it was almost impossible to keep the planned flight parameters. Despite that, the flight was successful and almost 1000 orthogonal and oblique images were obtained. Both 12 MP and 48 MP modes were used for the shooting of images. The whole flight lasted approximately 45 minutes and only two fully charged batteries were needed. For this flight, only one person was required (the pilot), but generally it is better when there is also a second person, who has a non-stop visual contact with the drone for the whole time of the flight and warns the pilot in case of a danger of accident. The overall time spent in the field was approximately 1 hour.

The next step was the data processing in the office. The first part consisted in the Structure-from-Motion processing in the Agisoft Metashape Professional software. After loading the photos and their orientation, the georeferencing was made. The GCPs were marked on the photos and the optimization of parameters was performed. After the optimization, the average error on GCPs was 4.6 cm, which is quite a satisfying value for a cadastral survey. The next step was a generation of a dense point cloud and a 3D model of the surveyed area with a texture (Fig. 5). The main product for the purposes of a cadastral survey is an orthomosaic (Fig. 6), which was generated after the 3D model was obtained. The surveyed area is practically without any buildings or fences, so there were not many distortions in the 3D model and the orthomosaic was relatively good. Although the GSD was approximately 5 mm, the resolution of the orthomosaic was chosen to 1 cm/pix in order to save the space on the harddisk. This resolution is sufficient enough for a cadastral survey. Another result which can be generated in this software is a high-resolution digital surface model (Fig. 7). In general, quite powerful PCs are needed for the SfM processing with multi-core processors and powerful graphical cards. In this case, it was a laptop equipped with an Intel Core i7 six-core processor and a Nvidia GeForce GTX 1050 graphical card. The whole processing lasted approximately one and a half hour.

Figure 5: Textured 3D model

Figure 6: Orthomosaic

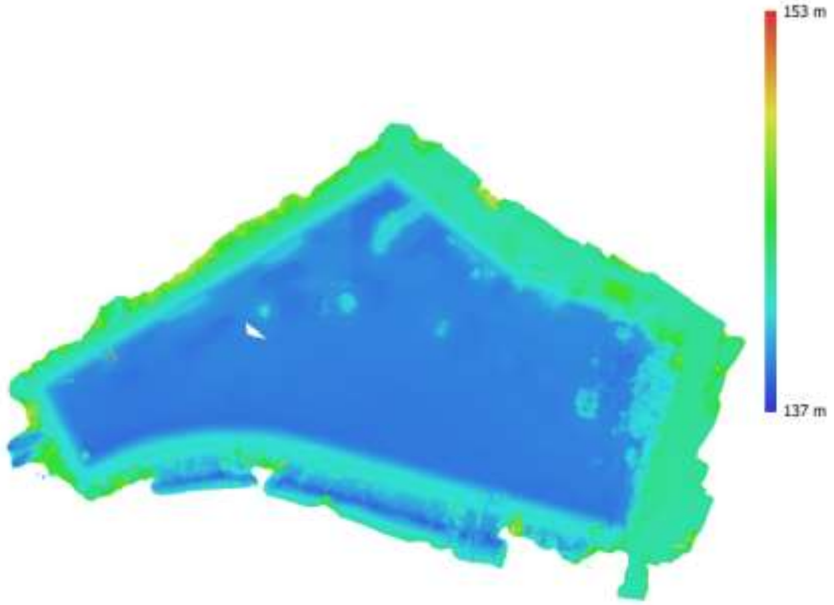

Figure 7: Digital surface model

Table 2: Precision evaluation of the UAV photogrammetry measurement

Point number	**Positional deviation (orthomosaic) [m]**	**Positional deviation (image) [m]**	**Quality code**
1400260048	0.06	0.06	3
1400260049	0.06	0.08	3
1400260161	0.09	0.05	3
1400260102	0.08	0.06	3
1400260103	0.08	0.06	3
1400260140	0.07	0.03	3
1400260139	0.09	0.09	3
1413150005	0.04	0.08	3
1413150011	0.04	0.05	3
1413150002	0.04	0.06	3
1413150001	0.02	0.05	3
1400220002	0.04	0.04	3
1400220001	0.10	0.06	3
1437960012	0.05	0.04	1
1400210003	0.01	0.06	3
RMSE [m]	0.064	0.061	–

The second step of the data processing consisted of obtaining the coordinates of the points for the cadastral survey. For the purpose of the precision evaluation of the UAV photogrammetry method, the position of 15 check points of cadastral boundaries (Fig. 8, green colour) was determined and compared with the points in the cadastral map. The positional deviations between the point determined by the UAV photogrammetry and the point in the cadastral map were calculated and, in the end, the RMSE value was obtained. Because the cadastre in the Slovak Republic is only two-dimensional, only the 2D precision in the X-Y plane was evaluated. The position of points can be obtained in several ways. In this evaluation, two methods were used. The first method is based on identification and measuring of the coordinates of a point on the orthomosaic (Fig. 9 left). In the second one, the points were identified and marked on several images in the Agisoft Metashape software, which calculated the position of the points using the orientation parameters (Fig. 9 right). The results can be seen in Table 2. Besides the positional deviations for the ortho-derived measurements (left side) and the image-derived measurements (right side), a point number in the cadastral map and a quality code is given for each point in Table 2. The quality code of a point gives us the information about the maximal allowed positional deviation (see chapter 2.1). After the precision evaluation, the fishpond edge has been extracted from the orthomosaic (Fig. 8, red colour).

Figure 8: Configuration of the check points used for the precision evaluation (green) and the new cadastral boundary extracted from the orthomosaic (red)

Figure 9: Measurement of point position on orthomosaic (left) and image (right)

The position of the check points was determined using two different options. The first was the identification and marking of the points on the georeferenced orthomosaic. The positional deviations between the measured points and points in the cadastral map are all less than 0.10 m, with most of them equal or less than 0.06 m. The RMSE value in this method of point extraction was 0.064 m. In the second option, where the points were identified and marked on several photos and their position was calculated by the photogrammetric software, the results were practically the same, with the maximal value 0.09 m. The RMSE value in this option was 0.061 m. In general, these results are very satisfying for the purposes of the cadastral survey according to the Slovak regulations. Most of the check points have the quality code value “3”, which means that the maximal allowed deviation between a new measurement and a point in the map is 0.24 m. All the results were well under this value, so in this case, the UAV photogrammetry method proved to be precise enough for the cadastral survey. The RMSE values are very good as well, which also supports this statement. However, it is possible that the results could be even better if the flight was performed in better weather conditions and the artificial markers were used as GCPs. This will be subject of a further research. The results of the second method of point extraction from images are slightly better, but the difference is not very high, which means that in this case, we can consider both methods equal.

One of the aims was to evaluate the overall effectiveness of this method. The whole process, which consisted of measuring and processing, lasted approximately two and a half hours. We do not have the data on the duration of the measurement and processing with “classical” surveying methods, but we presume that only the measurement of the fishpond edge in the field would last up to 3 hours. On the edge, there are many trees, and therefore the GNSS method could not be used there; consequently, a polar method with a total station would have to be used. This method is very time consuming because the selection of suitable stations, setting up the tripod and the measurement itself last a lot of time. For this method, at least two people are needed –one person who measures and another who signalize the points with a reflective prism. If we wanted to obtain a DSM of the bed of the fishpond, the measurement in the field would last even longer and the measurers would get wet and dirty. On the contrary, the measurement in the field with the UAV lasted only one hour and only one person was needed for it. The most crucial part of the UAV photogrammetry method is the processing in the office, which can take many hours for big areas. However, this processing is almost fully automatic, so it can be done even during the night. In general, the equipment used for the UAV photogrammetry is cheaper than the one used for the “classical” methods. Following all these facts, the UAV photogrammetry can be considered more effective for the cadastral survey than the “classical” surveying methods and it saves time and money. If we speak about the effectiveness of the point extraction, the extraction from orthomosaic is undoubtedly more effective than the extraction from images because on the orthomosaic, the point has to be identified and marked only once and in the image extraction, it has to be identified at least on 3 to 4 images. However, the extraction of points from the orthomosaic can be used only in the areas without buildings because the walls of the buildings, which are also cadastral boundaries, cannot be seen under the roofs on the orthomosaic. In this case, only the second option of extraction from images can be used to get precise results. Testing of the precision will also be subject of a further research.

The UAV photogrammetry method has some additional benefits in comparison to the "classical" surveying methods. It provides not only the coordinates of the points of cadastral boundaries but also some other additional results, such as a highly detailed textured 3D model (Fig. 5), a high-resolution digital surface model of the area (Fig. 7) or an orthomosaic (Fig. 6). These results can be used by numerous other professions in many applications. The additional results will also be important in the future for the building and development of a 3D cadastre in Slovakia. Another advantage of this method is that it is "contactless". The surveyor does not have to enter the properties and interact with the owners and the social distancing can be maintained, because the properties can be sensed from above with the UAV. This is very important in the time of a global pandemic, such as the Covid-19 pandemic.

4. CONCLUSIONS

For the purposes of a functioning land management system, it is necessary to have a precise and complex tool for the evidence of land use, such as the cadastre. Nowadays, the cadastre in the Slovak Republic consists of a lot of data of different quality and there is a need for a complex renewal of cadastral maps. However, with the "classical" surveying methods, the renewal is proceeding very slowly. There are also plans for a future launch of a 3D cadastre, for which these methods would be insufficient. New smart measurement methods are needed which would be more effective for the cadastral survey and would provide 3D information about the surveyed objects. One of these methods could be the UAV photogrammetry. This method was tested for the cadastral survey of a fishpond near Bratislava. The measurement was performed in early December 2020 with a DJI Mavic Air 2 drone. For the GCPs the GNSS-RTK method was used with a Leica GS08 receiver. The images were processed using a standard SfM procedure in Agisoft Metashape Professional software and the coordinates of points were extracted using two different methods. For the precision evaluation, 15 check points were used whose position is also known in the cadastral map. The precision proved to be very satisfying for the purposes of a cadastral survey according to Slovak regulations, which means that the method can be widely used. The overall effectiveness of the UAV photogrammetry was also evaluated. This method proved to be more effective than the "classical" surveying methods. It is less time-consuming and also cheaper because the equipment is affordable, and fewer people are needed for the measurement. The method has some additional benefits. Besides the coordinates of points, many other results can be generated, such as a 3D textured model or a digital surface model. These results can be used by a wide range of other professionals. All the information provided are three-dimensional, which is very important for the future launch of a 3D cadastre. The UAV photogrammetry method in a cadastral survey will be subject of a further research. In the future, it will be tested for the survey of a built-up area and then for bigger areas, which would consist in a simulation of a real cadastral mapping in a whole cadastral district. Other drones will also be used and the results will be compared.

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BIOGRAPHICAL NOTES

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