34. évfolyam (2024) 2. szám 155–168. • DOI: 10.32562/mkk.2024.2.11

MŰSZAKI
KATONAI
KÖZLÖNY

Emese Kutassy[1]

Comparison of UAV Orthophoto and Ground Survey at a Flood Protection Embankment

In the study, I compare the elevation data of points obtained from an orthophoto taken from a drone with the heights of points measured from the area by ground survey procedure and measuring station. I examine the usability of the points determined from the orthophoto for flood protection and for assessing flood protection embankments. I present the difficulties of assessing floodplains. The taking of orthophotographs and the data obtained from them may be important in determining the conditions after the floods have subsided and in detecting sediment deposition. My aim is to examine to what extent orthophotographs can be used to determine embankment heights in case of flooding, in order to avoid water overtopping of protective embankments.

Keywords: *flood, orthophoto, embankment height test*

Introduction

Hungary's geographical and hydrographical characteristics make it one of the most vulnerable European countries to flooding. Since the turn of the millennium, our rivers have experienced the highest flood levels, which has posed a major challenge for the country and its water services. As a direct consequence of climate change, hydrological hazards have become more extreme and less predictable, and more emphasis needs to be placed on preparedness.

In the context of increased risks, protection activities, emergency efforts and traditional preparedness, methods are placing a significant burden on the budget. It is therefore necessary to improve forecasting systems and increase the priority given to adaptive, preventive solutions. Flood protection is aimed at maintaining and improving state-owned protection works and carrying out protection tasks. Organised flood protection includes the technical tasks of protection. Such tasks include raising or relocating flood protection embankments to

1 Engineering teacher, Ludovika University of Public Service, Faculty of Water Sciences, e-mail: Kutassy.Emese@uni-nke.hu

increase and improve the drainage capacity of the floodplains, embankment regulation and control, bank protection, maintenance of river control works, etc.[2]

Modern tools of the modern age can be used to perform these tasks. Such tools include unmanned aerial vehicles (UAVs), commonly known as drones. In flood protection, drones can be used in a variety of ways, for information gathering, damage assessment, supporting rescue operations. Drones can be used to quickly and efficiently assess the areas affected by flooding and the damage caused, helping the authorities to assess the situation and take appropriate measures, as well as to plan recovery efforts efficiently.

Drones can provide a live view of the scene, which can help coordinate protection efforts and can also be used during rescue operations.

UAV usage control

It is important to note that the use of drones is subject to strict rules, and the licences and qualifications required to use them are set out in legislation.

Domestic legislation has been created in accordance with legislation of the European Union. The Hungarian legislation implementing Commission Delegated Regulation (EU) 2019/945 on unmanned aircraft systems and third-country operators of unmanned aircraft systems[3] and Commission Implementing Regulation (EU) 2019/947 on rules and procedures for unmanned aircraft operations:[4]

- Act CLXXIX of 2020 amending certain acts related to the operation of unmanned aircraft.[5]
- Government Decree No. 38/2021 (II. 2.) on the flight of unmanned state aircraft.[6]
- These regulations set out the requirements for flying drones, such as maximum altitudes, permitted areas and airworthiness requirements. Drone pilot training is required to fly drones. Upon successful completion of the exam, a certificate of competence will be issued to certify the qualification. When using a drone, liability insurance is also required to protect third parties and the owner, and registration as an operator of an unmanned aircraft system is also required.[7]

Aerial photography and orthophotography

An unmanned aircraft can "only" fly by itself. To be used in surveys, it is fitted with some kind of sensor. In this case, it is a camera to take aerial photographs, which can then be used to produce orthophotos that can be used for measurements.

2 Országos Vízügyi Főigazgatóság 2023.
3 Commission Delegated Regulation (EU) 2019/945.
4 Commission Implementing Regulation (EU) 2019/947.
5 Act CLXXIX of 2020.
6 Government Decree 38/2021 (II. 2.).
7 Légtér [s. a.].

Orthophotos are aerial photographs taken without the perspective and topographical distortions inherent in photography. Orthorectification allows aerial photographs to be free of distortions caused by photography, so that they are accurately positioned in geographic space. Orthophotographs can be used to make accurate measurements, because they show a perpendicular (orthogonal) projection of the earth's surface. These are excellent for mapping and surveying, because they represent the area without geometric distortions. The images themselves (which can be hundreds or thousands of images) can be stitched together in a suitable software to form orthoimagery.[8]

Photogrammetry is the discipline of measuring on photographs, which deals with the taking of photographs for measurement or data acquisition purposes and their possible processing. In photogrammetric evaluations, the relationship between overlapping images and the terrain is established by orienting the image pair using an internal or external orientation. The overlap between pairs of images is necessary because the overlapping areas are used to produce the spatial model[9] (during flight, many images are taken, and the images are built up from blocks or series of images). In order to perform the evaluation, at least 60% overlap between the image sequences is required, so that objects on the ground can be found in at least two images.[10] Photogrammetric evaluation is best used in locations where there is a clear view of the object or area, as this provides additional information for processing metric data. The advantages of photogrammetry are that the area to be surveyed does not need to be approached, the field work, the measurement time is relatively short, the measurement/observation of rapid phenomena is suitable, the resulting images contain significant quantitative and qualitative data and, last but not least, the evaluation of the data can be performed quickly and in an automated way.[11] In other words, we "bring the field" into the office.

Photogrammetry can be used to determine the position and size of the area surveyed and photographed. This discipline is mainly used for topographic surveys, but can also be used for other tasks.[12]

With the development of technology, photogrammetry is in its heyday, as both the cameras and the flying instruments that carry them and the software that processes them offer a wealth of possibilities. Before starting aerial photography with a drone, a flight plan of the area to be surveyed must be drawn up to determine, among other things, the flight altitude, the overlap of images within and between lines, the interval between shots, etc. There are simple correlations among them. Nowadays, various programs are used to calculate these and to produce a flight plan.

The photogrammetric evaluation depends to a large extent on the geodetic preparation. Using this procedure, control points are defined for the orthomosaics before the flight. These points should be positioned so that they can be easily identified in the images when referencing. An aerial triangulation shall be performed using the photogrammetry and geodetic

8 See: https://lechnerkozpont.hu/oldal/ortofotok-es-legifelvetelek
9 Engler 2008a: 16.
10 Engler 2008b: 11.
11 Krauter 2008: 3.
12 Engler 2010: 1.

control points in a consistent manner. Without control points, only simple geodetic point determination could be performed.[13]

Depending on the air triangulation you are working with, you choose the number of alignment points. This depends on whether you are performing array or row triangulation or point densification within a model. For this procedure, the main criterion is to have enough points for absolute orientation, which means a minimum of 5 points, comprising 2 horizontal and 3 vertical control points. Less than this is not allowed, but more is possible.[14]

The orientation of images is used to obtain spatial coordinates from the pixel coordinates of digital images, i.e. the positioning of the images in a given spatial coordinate system.[15]

Drones as tools for aerial photography

Aerial orthophotography by drone is a modern, now widespread and effective method of collecting geographic information, as well as mapping and terrain modelling. The use of drones enables the rapid and accurate capture of high-resolution aerial photographic data, which can then be processed and used to create maps and terrain models. In essence, drone orthophotography is a technological development that is revolutionising the collection and use of geographic data. The use of drones allows orthophotography to be produced quickly and cost-effectively, which has a number of advantages, and can be used in many areas in addition to mapping, such as flood protection, construction, agriculture, forestry, horticulture and archaeology.

Terrain recording with total station

Field geodetic measurements, 3D point determination can be produced most quickly with conventional instruments using measuring stations. For this reason, measuring stations are used for field surveys, as the only limits to surveying an area from a single point of view are the telemetry section and the terrain conditions. The measuring stations implement horizontal and vertical angle measurement, telemetry, storage, management, transformation and calculation of the measurement results in a single unit.[16]

The accuracy of the height determination is equivalent to trigonometric height measurement, which is appropriate for field surveys. Trigonometric altimetry is a method used in geodetic surveying to determine height differences. Its accuracy depends on the measurement conditions and the quality of the instrument, and can be measured to within a few centimetres of the ground, but exactness can be increased to millimetres. The advantages of trigonometric height measurement include the possibility of measuring large differences in

[13] Engler 2010: 6–8.
[14] Engler 2010: 8-10.
[15] Jancsó 2010: 3–5, 9.
[16] Kutassy 2021: 67–68.

height over small distances and the direct measurement of distant points. The disadvantage is that it requires knowledge of distance – hence the importance of distance accuracy – and is generally less accurate than levelling.[17]

The law of propagation of error is used to calculate the reliability of trigonometric height measurement:

$$\mu_{\Delta m} = \sqrt{\mu_h^2 + \mu_l^2 + \tan\alpha^2 * \mu_d^2 + \left(\frac{d}{\cos\alpha^2}\right)^2 * \frac{\mu_\alpha^2}{\rho^2} + \left(\frac{d^2}{2r}\right) * \mu_k^2}$$

where
μ_h is the instrument height,
μ_l is the signal height,
μ_α is the mean error of the altitude angle measurement,
μ_k is the mean error of refraction coefficient, usually taken as μ_k = +/– 0.05

Up to a distance of 400 metres, µΔm = +/– 0.01 m, up to a distance of about 4 kilometres, a reliability of around µΔm = +/–0.10 m can be achieved with the appropriate measurement technique.[18]

Figure 1: Location of the sample area
Source: edited by the author from Google Maps

[17] Takács 2017.
[18] Tarsoly 2010: 22.

Measurements

For comparative measurements, I have selected an 500 m long stretch along the Baja–Foktő reach of the main flood protection embankment No. 03.02 between Dusnok and the M9 main road, located between embankment km sections 27 and 26.5 (Figure 1).

The whole 03.02 protection line falls within the area of operation of the Lower Danube Valley Water Management Directorate. The protection section protects Dusnok, Fajsz, Bátya, Miske, Hillye, Drágszél, Homokmégy, Alsómégy, Halom, Öregcsertő, Csorna, Negyvenszállás, Foktő, Kalocsa, and the lower-lying parts of the highland settlements. The construction of defence section 03.02 started in the 1930s. The embankments were built and reinforced under the direction of the Pest County Sárközi Flood Relief Society, founded in 1872. The reinforcement of the embankments fell short of the necessary safe construction. In the case of some devastating floods, the increase in defensive capacity was limited to filling in the height gaps. Even today, the damaging effects of irregular elevations and inadequate construction technology can cause unexpected surprises in flood defences. Poor subsoil, foundation and compaction failures, etc. can significantly reduce the stability of the embankment. This section has been subject to 19 major floods from 1876 to the present, 13 of which were summer floods and 6 winter/ice floods, the most notable being the Great Danube Flood of 1956 and the summer floods of 2013. The embankment crest is 6.0 m wide, with a 1:3 slope on the water side and a 1:4 slope on the flood protection side, with a 40 m wide buffer zone.

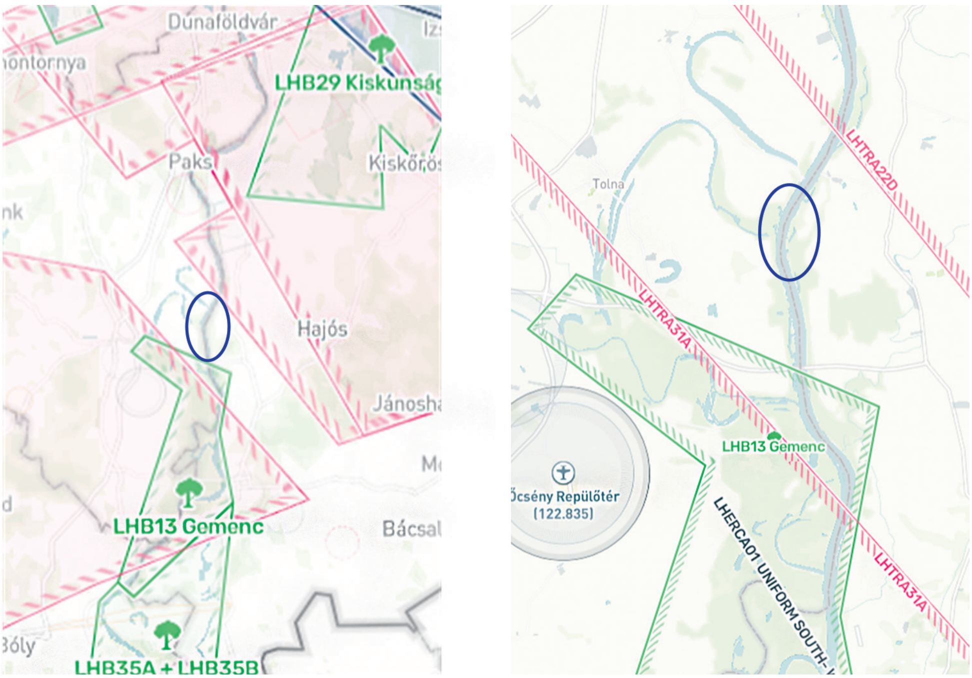

Figure 2: Selecting a sample area on airspace.com
Source: compiled by the author based on legter.hu

Plan for survey plot

I have designated the area to make the use of the unmanned aircraft legally and easily, so I have chosen this part of the site because it does not require an incidental airspace or a nature reserve permit, and it does not affect any inhabited area (Figure 2).

I selected and activated the area for the flight via the Mydronespace app. I took the airspace map on airspace.hu into account when selecting the sample area.

For the survey, I used a Leica MS60 robotic measuring station, a Leica Viva GS14 GNSS receiver and a DJI Phantom 4 drone.

Measurement with robotic total station

The robotic measuring station is a 1" angular measurement and 1 mm + 1.5 ppm distance measuring accuracy device, so I used the ground survey as a basis for the processing.[19]

The measuring station was used to survey the embankment section by section with its feature points such as the embankment foot, crown edge, crown axis, the edge and axis line of the embankment casing, which typically coincided with the crown axis line, and the feature points of the embankment, as well as field points on both sides. I also measured the alignment points for the orthophotos, and I measured the latter with a GNSS receiver, too. There were no significant differences between the two determinations. To facilitate and clarify the processing, I used codes to distinguish the detail points.

The processing of the points of the approximately 500 m long embankment section surveyed with the measuring station was carried out in AutoCAD Civil 3D. From the processed points, I created a Triangulated Irregular Network (TIN) surface based on the coding.[20]

From this surface, elevation values can be determined, which is a good basis for comparing the data generated by orthophotos.

Survey with UAV

For the survey with UAV, I prepared a flight plan of the area to be flown in Pix4D Capture the day before the flight, which I checked before the flight to ensure that the settings and calibration data were appropriate for the field conditions. After pre-flight checks, I plotted and mapped the area to be flown using MyDroneSpace. The survey was conducted at an elevation of 60 metres above ground surface.

After the survey, I used Drone2Map and ArcGIS – ArcMap to process the data. I started the processing with Drone2Map, a desktop application developed by the Environmental Systems Research Institute (ESRI) that can be used to produce orthophotos from aerial photographs,

[19] See: https://leica-geosystems.com/hu-hu/products/total-stations/multistation/leica-nova-ms60

[20] See: http://docs.autodesk.com/CIV3D/2012/HUN/filesCUG/GUID-C26F9546-BD41-4DE2-BF50-DA262A-91C4E-837.htm

as well as 2D and 3D maps of landmarks and areas that cannot be accessed or fully covered due to size or terrain.

The data thus extracted was further analysed and examined in desktop for ArcGIS – ArcMap (ESRI), one of the most widely used GIS software worldwide.[21]

Figure 3: Height differences of orthophoto points
Source: compiled by the author

Results

The results of the ground survey were compared with the altitudes derived from the orthophoto. Out of the 22 sections surveyed, 19 sections had points with a difference of up to 10 cm between the two values (Figure 3). As my investigation is focused on the use of orthophotography to determine the embankment height, I considered those with differences of less than 5 cm between two surveys as acceptable values. In addition to this, I have also investigated differences of between 5 and 10 cm to test the acceptability of the digital elevation model.

---

[21] Márkus 2010: 8–11.

The following results were obtained as a percentage distribution:

54% of the points in the cover had a difference of less than 5 cm, 27% between 5 and 10 cm and 16% fell in the interval between 10 and 20 cm, with only 4% having a larger difference.

Of these, 20% are not suitable for major surveys (Figure 4).

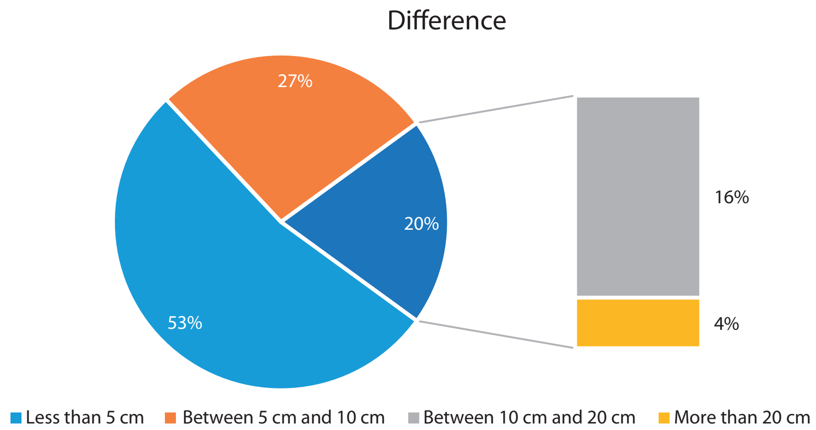

Figure 4: Percentage distribution of Asphalt points
Source: compiled by the author

The differences at the field points show a much more negative picture. Only 26% of the points had a deviation of less than 5 cm, 22% of the points fell into the 5 to 10 cm range, while the number of points that were unusable/out of tolerance increased significantly, reaching a combined value of 52%, i.e. more than half of the points surveyed (Figure 5).

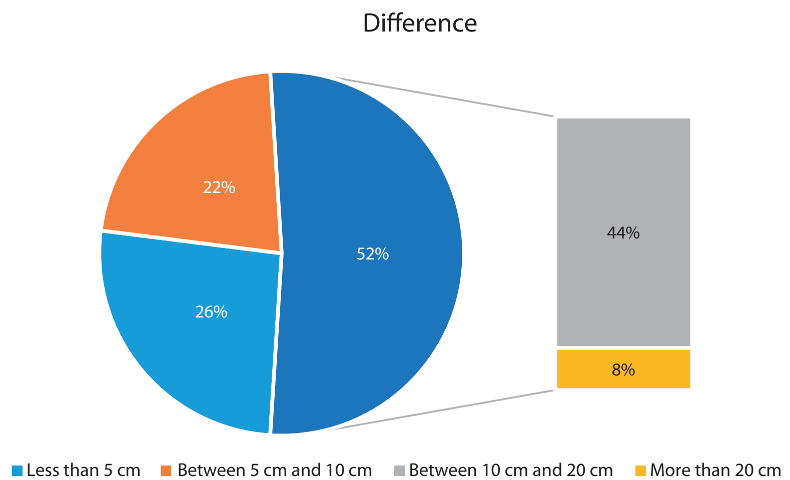

Figure 5: Percentage distribution of field points
Source: compiled by the author

The percentage of usable points on the crown edge has now reached 30%, but the percentage of unusable points has reached a high of 40% (Figure 6).

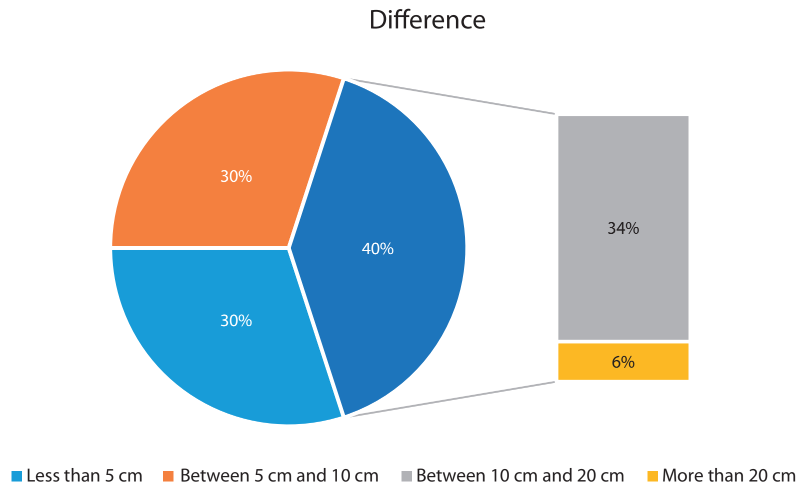

Figure 6: Percentage distribution of points on the crown edge
Source: compiled by the author

The percentage of points below 5 cm at the bottom of the slope is 34%, and the percentage of points between 5 and 10 cm, which are still acceptable, is also at this level. The percentage of non-compliant deviations here is 31% (Figure 7).

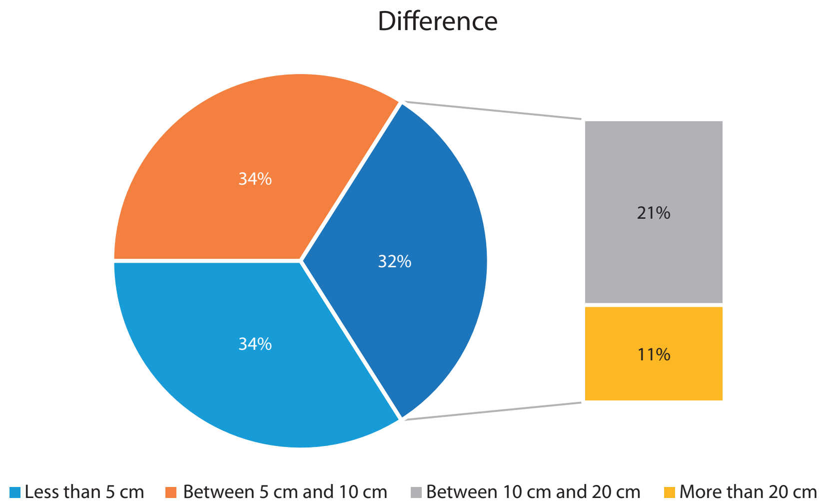

Figure 7: Percentage distribution of points at the bottom of the slope
Source: compiled by the author

For points measured in the slope, the proportion of points below 5 cm is 35%, and for points between 5–10 cm is 27%. These points also have a high percentage of unusable points, 37%. (Figure 8).

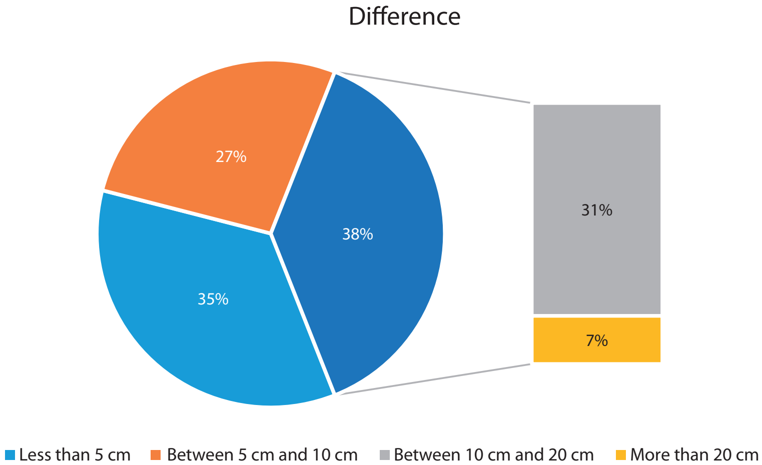

Figure 8: Percentage distribution of points in the slope
Source: compiled by the author

For further analysis, I used the Digital Elevation Model (DEM) created from orthophotos.

I created the TIN surface from which I extracted a raster file in TIFF format.

From the survey using two different technologies, I thus obtained two DEMs that are suitable for comparison, and the difference between the two surfaces can be used to illustrate the difference between the two technologies.

I have taken the surface from the ground survey as a basis and adjusted the surface extracted from the orthophoto so that the two surfaces overlap completely. I then created the difference surface. I used the programs AutoCad Civil 3D and ArcMap.

When examining the difference surface, I found that the areas with a maximum deviation of 5 centimetres account for only 18.6% of the total area (Figure 9). This means that the model created from the drone orthophoto is not suitable for accurately determining the height of embankments, as the percentage of areas within the margin of error is extremely low.

The difference surface area was similar for differences of 5–10 cm. In this case, the area where the deviation is less than 10 cm is also small. Around 15.4% of the area covered meets this criterion. Thus, deviations not exceeding 10 cm amount to about 34% of the total area.

Still, if deviations below 10 cm were already in good proportion, orthophoto evaluation could not be used for flood control, because this value is already significant for embankment overtopping during flood control. However, a difference of 10 cm could be accurate enough for topographic surveys, which would mean that photogrammetry evaluation could be useful for floodplain surveys. However, this presupposes further investigation (Figure 9).

In 97.1% of the surveyed area, the maximum deviation is less than 1 m, which may be suitable for planning or reconnaissance tasks where this accuracy is acceptable (Figure 10).

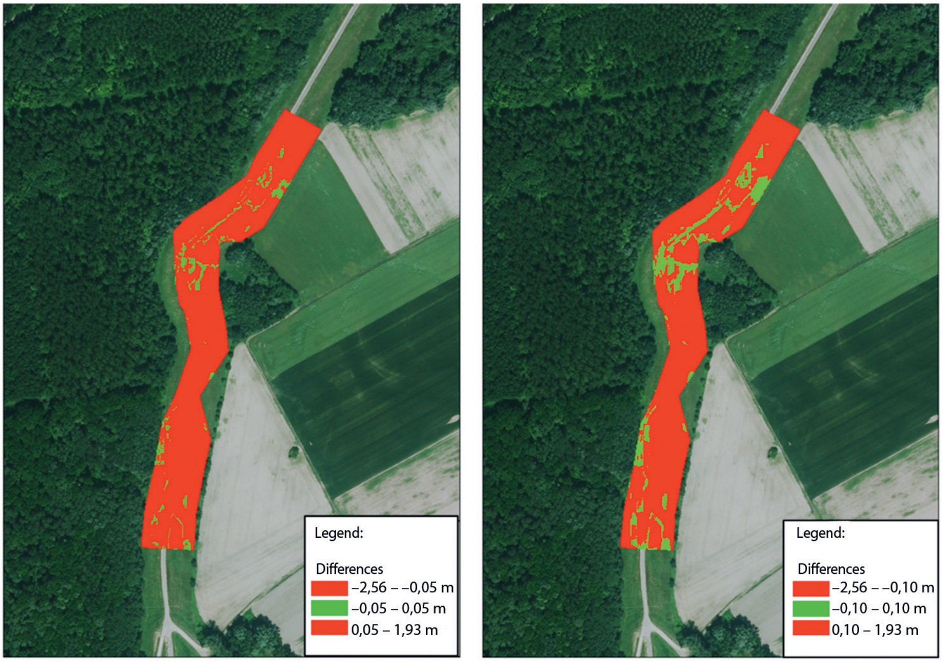

Figure 9: Evolution of tolerance for 5 centimetres and 10 centimetres
Source: compiled by the author

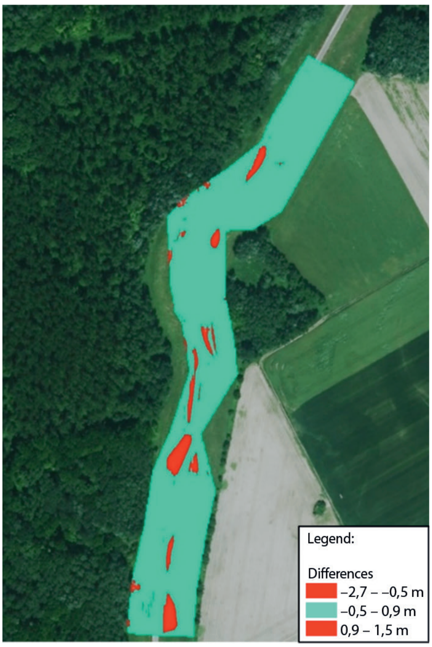

Figure 10: Error values less than 1 m
Source: compiled by the author

Summary

From the results presented above, it is clear that the pavement shows the best results. For areas covered by vegetation, such as field points, slope points, crown edges, the percentage of deviations not exceeding 5 cm is around 30%, i.e. about 70% of the points tested did not meet the expected criterion. One explanation for this may be that, while in the case of the ground survey, I was indeed measuring the field point, the ground surface itself, in the case of the orthophoto evaluation, the extent of the vegetation could not be fully taken into account, as their height is not homogeneous. (In my opinion, a comparison with Light Detection and Ranging –LiDAR – images would show different or better results. This could be a future task.)

Another option to explore in the future is the location and height determination of interface points. The interface points were determined using total station and GNSS technology. For orthophoto matching, the heights measured with the total station were used, the accuracy of which corresponds to trigonometry height measurements. If the height of the points is determined by levelling, the height fitting can also be improved.

According to the results of my study, the orthophotos taken by unmanned aircraft are not suitable for predicting the flood overtopping of protective structures. The data obtained from such orthophotos are generally not sufficiently accurate for precise geodetic surveys due to the 5 cm margin of error required in the hydrological domain. The percentage of areas within this margin of error is low, only 18.6% of the total area.

The rate of deviations within 10 centimeters is also unsatisfactory for a topographic survey based on the present results. However, further studies are needed before orthophotographs taken with a drone can be used for topographic surveying. The aim of my investigation was primarily flood protection embankments and not floodplains. In particular, how accurately the height of the embankment can be determined in the event of a flood to predict where water may cross the embankment, and what are the critical places where increased protection is needed during that time.

Unmanned Aerial Vehicles (UAVs) are excellent to prevent or remedy emergencies in the water management area, and they can be useful for flood protection. These can be used primarily to determine the location and horizontal extent of an emergency, to estimate the territorial extent of such phenomena, and to estimate and determine the area of influence of phenomena that have already occurred. For example, the detection of flood protection phenomena (boils, trickles, leaks) on the saved side, their location, and the survey of already flooded areas.

References

Engler, Péter (2008a): *A légi fotogrammetriai technológia.* Budapest: Nemzeti Szakképzési és Felnőttképzési Intézet.

Engler, Péter (2008b): *A fotogrammetriai információszerzés eszközei, módszerei.* Budapest: Nemzeti Szakképzési és Felnőttképzési Intézet.

Engler, Péter (2010): *Általános fotogrammetriai technológia.* Székesfehérvár: Nyugat-magyarországi Egyetem Geoinformatikai kar.
Jancsó, Tamás (2010): *Tájékozás.* Székesfehérvár: Nyugat-magyarországi Egyetem Geoinformatikai kar.
Krauter, Erika (2008): *A földi fotogrammetriai technológia.* Budapest: Nemzeti Szakképzési és Felnőttképzési Intézet.
Kutassy, Emese (2021): *Geodéziai alapismeretek II.* Budapest: Ludovika.
Lechner Tudásközpont: *Ortofotók. légifelvételek.* Online: https://lechnerkozpont.hu/oldal/ortofotok-es-legifelvetelek
Drón törvény 2021 – érthetően szakértőktől. *Légtér,* [s. a.]. Online: https://legter.hu/blog/dron-torveny-2021-erthetoen-szakertoktol/
Márkus, Béla (2010): *Térinformatikai ismeretek 7. Alkalmazások és szoftverek.* Székesfehérvár: Nyugat-magyarországi Egyetem Geoinformatikai Kar. Online: https://dtk.tankonyvtar.hu/xmlui/bitstream/handle/123456789/7803/0027_TEII7.pdf?sequence=1&isAllowed=y
Országos Vízügyi Főigazgatóság (2023): *Árvízvédelem.* Online: www.ovf.hu/arvizvedelem-vizkarelharitas/arvizvedelem/arvizvedelem
Szőke, Márk (2022): *UAV geodéziai célú felhasználása a vízügyi ágazatban.* szakdolgozat Nemzeti Közszolgálati Egyetem Víztudományi Kar
Takács, Bence (2017): *Geodézia építészeknek.* Budapest: Budapesti Műszaki és Gazdaságtzdományi Egyetem.
Tarsoly, Péter 2010: *Geodézia 10. A trigonometriai magasságmérés.* Székesfehérvár: Nyugat-magyarországi Egyetem Geoinformatikai Kar.

Legal sources

Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems
Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft
Act CLXXIX of 2020 amending certain acts related to the operation of unmanned aircraft
Government Decree 38/2021 (II. 2.) on the flight of unmanned state aircraft