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TESTING OF AVAILABLE MEASUREMENT METHODS FOR CUBATURE CALCULATIONS

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ABSTRACT

This article focuses on efficient methods for measuring volume, especially cubature control in landfill inspections. Several technologies were tested involving GNSS, UAV photogrammetry, UAV laser scanning, and videogrammetry to find a technology that enables fast and accurate data collection. The research was focused as a help for the Czech Environmental Inspectorate. These methods were compared using processed point clouds and volume calculations in 3Dsurvey software, evaluating their accuracy, cost, and technical requirements. Results show that UAV photogrammetry and videogrammetry allow quick data collection with minimal effort and price, while GNSS provides precise georeferencing but has limitations in surface modelling. Laser scanning with UAV is precise, but expensive for typical users. The processed point clouds were analysed for volume estimation accuracy, confirming their suitability for landfill monitoring. This article helps optimize geodetic methods for environmental inspections, highlighting the strengths and weaknesses of each approach. The findings provide valuable guidance for selecting the most suitable technologies in geodetic and environmental applications.

KEYWORDS

GNSS, Emlid, 3Dsurvey, UAV photogrammetry, videogrammetry, volumes, L1 lidar, point cloud

INTRODUCTION

Geodesy covers a wide range of methods and has applications in many areas of human activity. One of them is volume computing using geodetic methods, which incorporates a range of advanced technologies and techniques designed to accurately measure and analyse three-dimensional data for various applications in geodesy, engineering, environmental monitoring, and natural resource management. Central to this process is the use of Geographic Information Systems (GIS), which integrates spatial data with computational tools to analyse topography, elevation, and terrain. GIS allows for the visualization and manipulation of geographic data in 2D and more recently in 3D formats, providing a platform for the creation of digital elevation models (DEMs) or digital surface models (DSMs) that form the foundation for volume calculations.

Remote sensing technologies such as LiDAR (Light Detection and Ranging) and photogrammetry have revolutionized volume computation. LiDAR, which uses laser pulses to measure distances to the Earth's surface, generates highly accurate 3D point clouds that capture detailed topographic features, even in dense vegetation or difficult terrain. Photogrammetry, which involves the use of overlapping aerial or satellite imagery, is another powerful tool for deriving 3D models of the landscape. These remote sensing methods, when combined with GIS, allow for precise volume calculations of natural and man-made features, such as mountains, rivers, reservoirs, excavation sites, and construction projects.

Additionally, Global Navigation Satellite Systems (GNSS) play a critical role in volume computing. GNSS provides highly accurate georeferencing and positioning data that is essential for precise surveying and mapping. Surveying equipment, such as total stations and digital levels, can complement GNSS by collecting high-precision elevation data, which is then used in volume computation for smaller-scale projects or areas where satellite-based data may not be sufficient. The integration of these technologies allows for the efficient and accurate computation of volumes, whether for land reclamation, flood modelling, mining, or construction, offering significant advantages in terms of speed, cost-effectiveness, and accuracy. Furthermore, the use of software platforms that can process large datasets, such as AutoCAD, ArcGIS, and specialized volume calculation tools, enables professionals to automate and optimize the volume estimation process. How it was written, determination of cubature is one of the disciplines that geodesy is dedicated to. Its determination can be done in several ways and by several methods.

Cubature can be calculated classically by geodetical measuring ways using total stations, formerly with theodolites and measuring tapes [1], or by other geodetically methods like photogrammetry. New modern method of digital photogrammetry and laser scanning give us better solution which is more precise and easier to use.

Aerial analogue photogrammetry has been used for a long time, for example, to monitor opencast mining activities, especially in brown coal mining areas. Terrestrial analogue photogrammetry then for computing cubature in quarries or sand pits. In nineties of 20th century modern digital photogrammetry began to be used based on scanned analogue images. After new Millenium automated digital photogrammetry based on SfM (Structure from Motion) and MVS (Multi View Stereo) has become very popular [2].

This includes terrestrial photogrammetry methods, but also the very popular drone technology. Much of the research has been focused on determining the cubature of forest stands. Pavelka et al. dealt with the topic of volume calculation, but they were more interested in comparing the RPAS method with other geodetic methods [3]. The use of digital aerial photogrammetry is mentioned e.g. by Kovanič et al. [4]. Tomljanović, et al discuss problems and using of drones in forestry [5].

Other technology used is laser scanning in terrestrial aerial or mobile applications. Mobile mapping especially as personal handheld technology seems to be very useful and popular in recent years. Běloch et al. analyses using and precision of mobile laser scanning [6], Štroner et al use drones with lidar sensor for volume calculations. Integration of DJI Zenmuse L1 LiDAR with Photogrammetry Software for Enhanced Data Acquisition, explored the integration of the DJI Zenmuse L1 LiDAR system for improved data acquisition and processing. The findings demonstrated the system's effectiveness in capturing detailed terrain information and generating precise digital models [7].

Another method common in surveying is the use of GNSS. For example, Emlid's Reach RS3 technology was tested by Oniga et al to verify whether it makes sense to use ground control points (GCP) in drone photogramnmetry for building model [8]. Using GNSS for monitoring or collecting geographical data is typical in technical or geographical practice [9], [10].

Lian et al explore a new non-contact targeting technology, namely videogrammetry. They discuss the principles, processes, and typical examples of its application. It is also one of the most significant sources for understanding the functioning of videogrammetry [11]. The videogrammetry method, which can be considered one of the most accessible and inexpensive, has been used in computer vision calculations in forest exploration, where it has played a major role in collecting date [12].

It is necessary to mention the data collecting with UAV in general. Drone cameras, such as the P1 photogrammetric camera from DJI, give a large possibility of using in urban planning for example. Its quality was investigated at HafenCity University Hamburg, where it was flown over the test area and compared, among other things, with the LiDAR L1, also from DJI [13].

The research highlighted the system's capability to produce high-quality digital terrain models and its suitability for various surveying tasks. Next article compared different UAV-LiDAR systems, including the DJI Zenmuse L1, for environmental monitoring purposes. The study emphasized the importance of selecting appropriate processing software, such as 3Dsurvey, to achieve accurate results [14], [15]. The result of the calculations is then a digital terrain model that is then compared. Reportedly, 3Dsurvey uses the same method of model calculation as described by Guo et al, , who described it as a regular pyramid hierarchy [16].

In the Czech Republic, there is a precise digital relief model (DMR 5G) of the entire country, which can be used by people for free. But it has a limited resolution (1-2 points on sqr. meter in open landscape) and accuracy (the reported mean squared height error is 0.18 m in exposed terrain and 0.30 m in wooded terrain), and it is more than 12 years old. The inspection people were also interested in comparing it with this model, because they often get into situations where they discover a black dump and need to compare the surface before and after contamination. DMR 5G is the subject of an article that discusses its use for other state mapping work [17]. All the methods described above show, among other things, how surveying is moving into completely different dimensions than it was ten to fifteen years ago. The problem of effectively educating the modern surveyor is addressed in [18]. This article may also point out that what was previously done only by a surveyor can now be done by another worker after training. In this research the 3Dsurvey software was used for computing of cubature calculations [19].

METHODS

A total of four measurement methods were used, which included the terrestrial and aerial variants. The methods were chosen to be the least demanding for the surveyor, field measurements and greater knowledge.

Test area

A test site was used to investigate the usability of the technologies and to compare their financial performance. The test site selected was city the Radim landfill in the Central Bohemian Region.

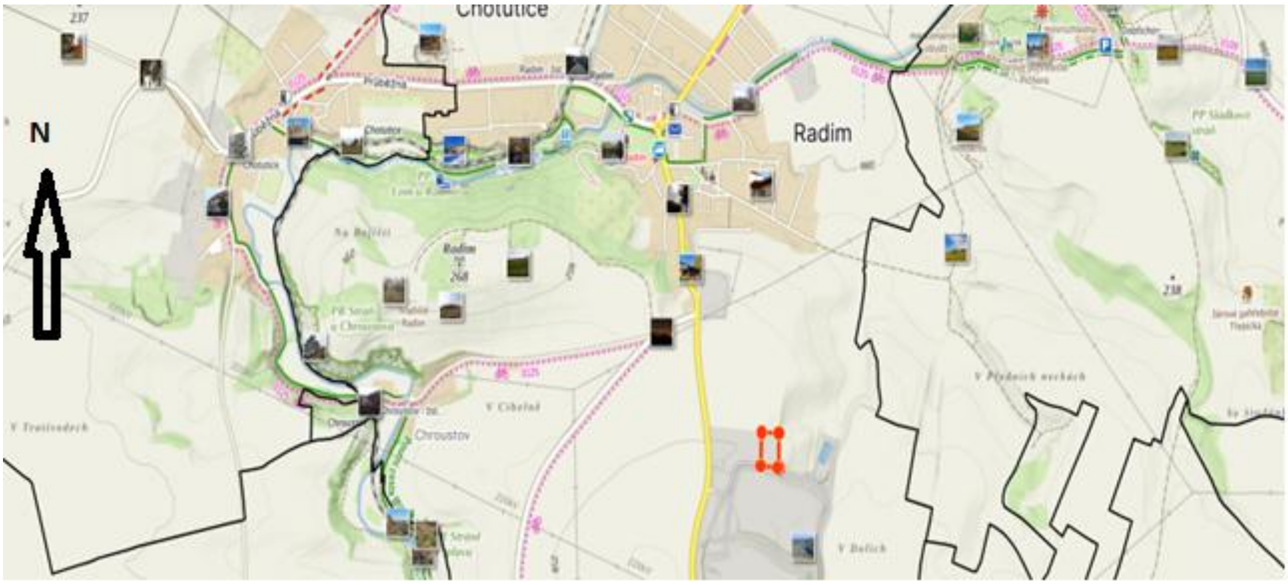

Fig.1 - Map of tested area, Radim, screenshot from https://mapy.cz, [50°03'49.7"N 15°01'01.4"E]

Fig.2 - Preparation by DJI M300, Emlid RS3 base station and 3gon Positioning worker, photo by O.Váňa

Used technology

GNSS

GNSS technology Emlid Reach RS3 was used. It was chosen because it is easier to operate for the general user. Anyone can download the app to their mobile phone. In RTK mode, the technology measures H: 7 mm + 1 ppm and V: 14 mm + 1 ppm. At the same time, it can measure with a tilt angle of maximal 60°, making the worker's job easier by not having to hold the spirit level [20].

Fig.3 - GNSS Emlid RS3, photo by O. Váňa

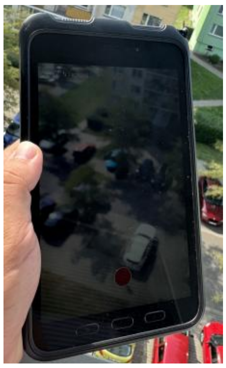

Fig.4 - Samsung Galaxy TAB 3, photo by O. Váňa

UAV - Photogrammetry

Photogrammetry was used twice. From DJI compan, the Zenmuse P1 and Mavic 3 Enterprise sensors were used. The DJI P1 sensor has a pixel size of 4.4 μm, 45MPix, 3-axis stabilization system and an aperture range of f/2.8-f/16. The carrier drone was the DJI Matrice 300 RTK. The DJI P1 was connected to an Emlid base station - for the purpose of collecting correction data [21].

Fig.5 - DJI P1, Heliguy.com

Fig.6 - DJI M3E, DJI.com

Fig.7-DJI L1, Heliguy.com

Mavic 3 Enterprise (M3E) incorporates a 4/3 CMOS sensor with 20MPix and with aperture range f/2.8-f/16. This drone was flown on an RTK correction connection through private provider TopNET [22].

UAV - LiDAR

DJI Zenmuse L1 sensor was used as the technology with LiDAR data collection. As in the case of M3E, it was also subject to corrections from the TopNET provider. The DJI L1 has an accuracy of around 3cm in point position at 100 m, 240,000 points per second, ideally from the altitude 50 m above the ground. It uses an RGB camera to colour the point cloud. Its disadvantage is that it must be computed in DJI's software, namely TERRA. This is not the case for photogrammetry [20].

Videogrammetry

The video record was done with a Samsung Galaxy TAB 3 tablet, which was installed with 3Dsurvey software and Emlid Flow application, which turns the GNSS RS3 into a mock location. The software on the tablet then records the video and telemetry data. The result is then a video with the camera location data at a specific time. Accuracy is determined by the quality of the captured video and the lens in the tablet.

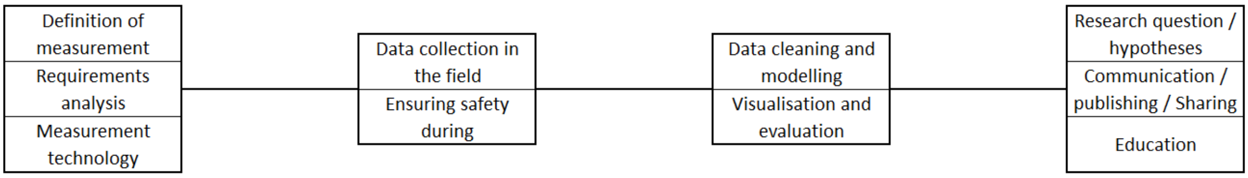

Fig.8 - Processing flow chart

DATA COLLECTION

To ensure accurate volume calculations, multiple geodetic measurement techniques were employed, as detailed in the previous section. A crucial aspect of data collection was the meticulous planning of aerial surveys, optimization of image overlap, and strategic placement of photogrammetric control points.

Planning of Aerial Missions

The aerial missions were carefully designed considering the characteristics of the surveyed area, the required resolution, and the available technological capabilities. For UAV-based photogrammetry, an optimal flight altitude of 50 meters was determined to achieve the desired Ground Sampling Distance (GSD). The flight trajectories were structured to ensure uniform coverage of the target area while maintaining adequate image overlap, as detailed below.

Image Acquisition and Resolution

A total of 250 images were captured with UAV DJI M3E, and 184 images with the DJI P1, providing a sufficient density of points for subsequent processing in 3Dsurvey software.

In addition to standard photogrammetry, videogrammetry was employed using a high-frame-rate recording device. Although videogrammetry generally exhibits lower data fidelity compared to conventional snapshot-based photogrammetry, its precision remains adequate for volumetric computations.

Flight time for DJI M3E was 12 minutes, for DJI P1 with Matrice 300 RTK carrier 15 minutes and for L1 LiDAR 14 minutes. Flight altitude was typically 50 metres.

Image Overlap Optimization

To enhance reconstruction accuracy, UAV photogrammetry adopted 80% lateral overlap and 70% longitudinal overlap between images. These parameters were selected based on established theoretical knowledge to maximize data redundancy and ensure precise point triangulation for 3D modelling. It was used by both photogrammetrical systems.

Control Points for Accuracy Enhancement

Control points were systematically distributed across the surveyed terrain, with a higher concentration in regions exhibiting pronounced topographic variations. A total of six GCPs were employed, measured using GNSS technology with a 2–3 cm spatial precision. The measurements were conducted using EMLID GNSS receivers in RTK mode, leveraging internet-based corrections.

Fig.9 - Placement of Ground Control Points, by O. Váňa

RESULTS

Processing of all data was done in 3Dsurvey software. Both photogrammetry and videogrammetry data processing were made and then calculation of terrain model and subsequent calculation of cubature.

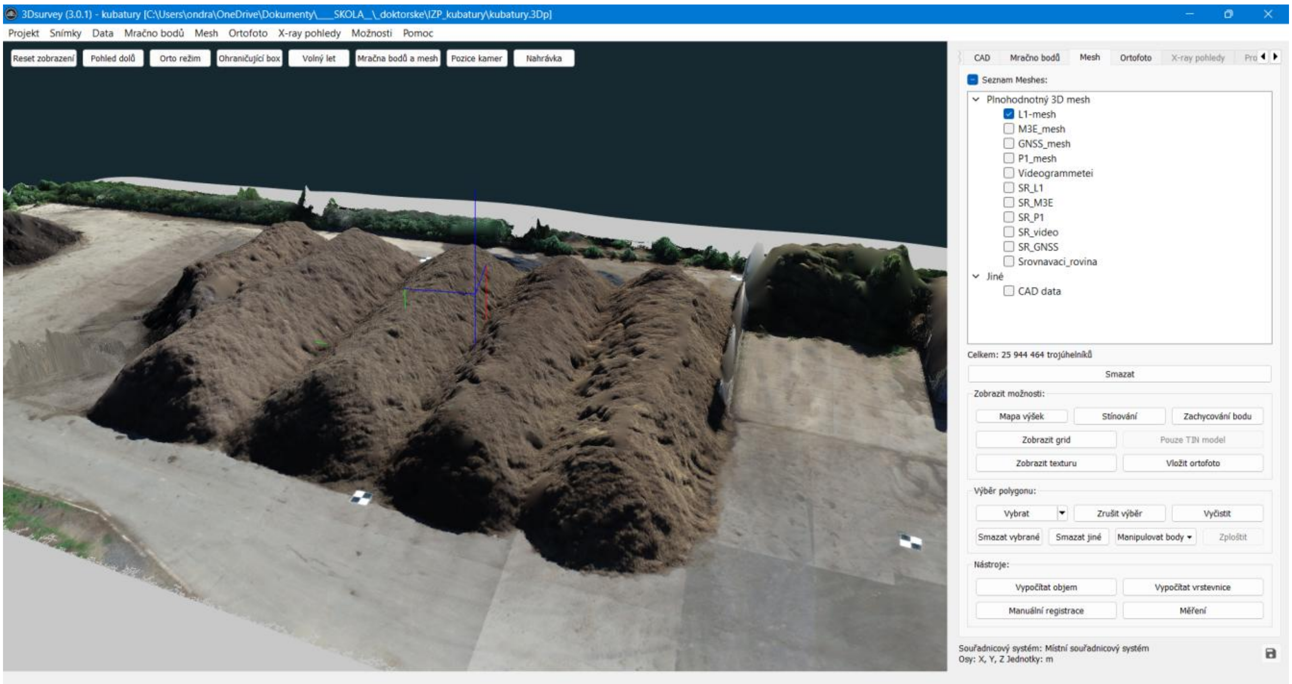

Fig.10 - 3Dsurvey, DJI L1 technologies, DSM reduction model - 25,944,464 triangles, by O. Váňa

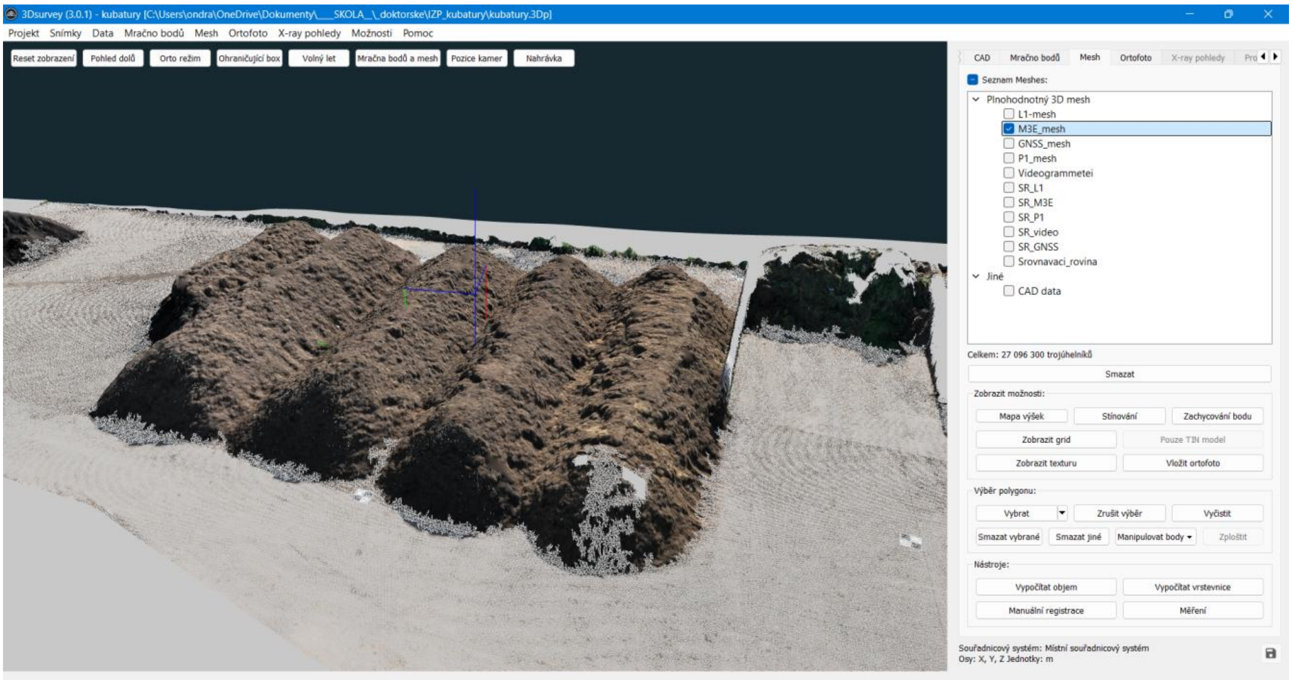

Fig.11 - 3Dsurvey, DJI M3E technologies, DSM reduction model - 27,096,300 triangles, by O. Váňa

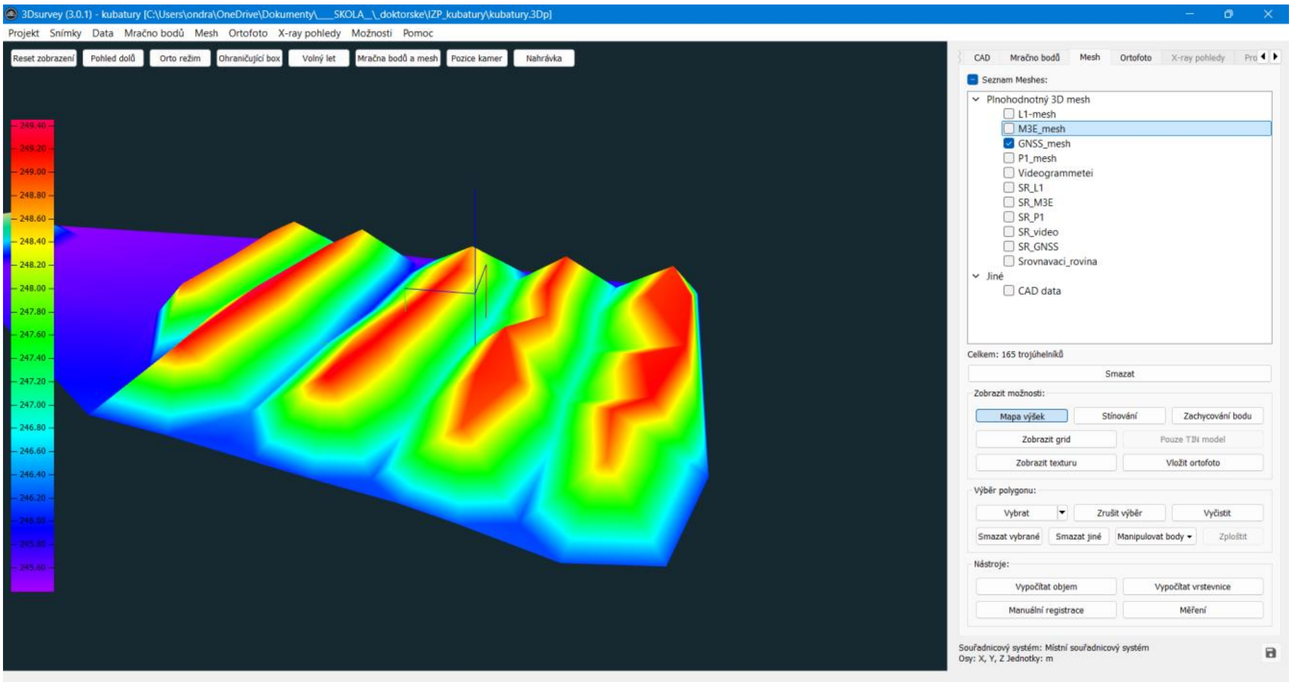

Fig.12 - 3Dsurvey, GNSS technologies, DSM reduction model - 165 triangles, by O. Váňa

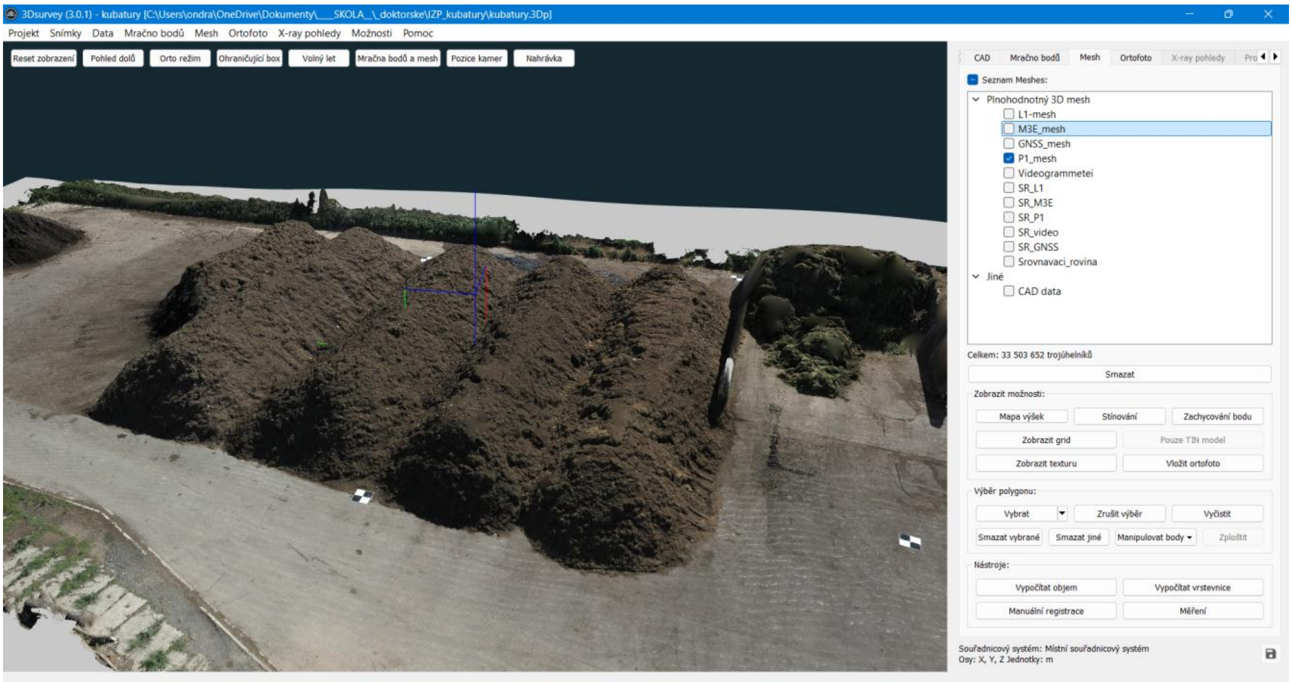

Fig.13 - 3Dsurvey, DJI P1 technologies, DSM reduction model - 33,503,652 triangles, by O.Váňa

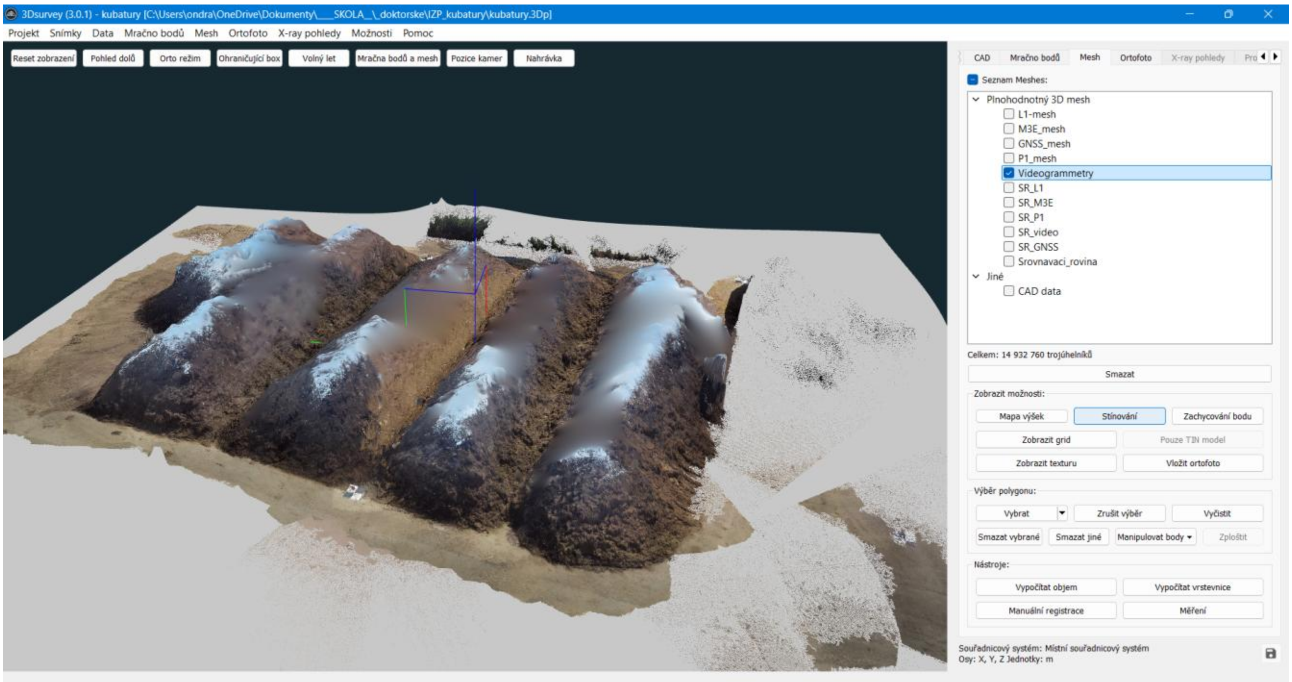

Fig.14 - 3Dsurvey, Videogrammetry technologies, DSM reduction model - 14,932,760 triangles, by O.Váňa

This software is a robust software where photogrammetry, videogrammetry, processed LiDAR data and a list of coordinates from GNSS measurements were calculated. The software can also calculate a terrain model from these measurements so that everything can be compared. All measurement methods were in the Czech Mandatory Coordinate System S-JTSK and altitude Bpv. The main comparison pile was the middle part. The comparison plane here was the height of the concrete surface for each measurement separately and the data taken from the DMR 5G. The first testing was to check the DMR 5G heights against the GNSS Emlid RS3 and M3E measurements, which are sufficient for verification, as the remaining P1, L1 and videogrammetry methods are based on GNSS Emlid RS3 measurements. This testing is very important for the environmental inspectorate, because many times they must look for the original condition before the material was buried and therefore must calculate the change of the original terrain.

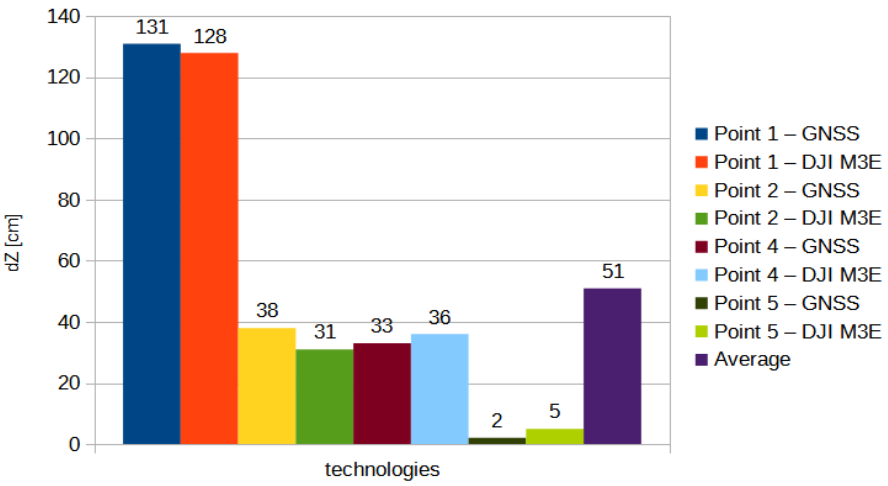

Fig.15– Graph comparing the height of a selected point in the area surrounding the landfill, always using two independent technologies with DMR 5G.

The inspection, which verifies the accuracy of landfill volumes, uses DMR5G as a reference from the time when the landfill did not exist, i.e., the original terrain. For smaller landfills, the accuracy of the original terrain is essential for accurately deriving the landfill volume. In this case, a total of 5 points were surveyed in the area around the landfill using various technologies (see Figure 15) to verify the accuracy and reliability of DMR5G locally. The points were selected at random, and 5 points is not a large number and depends on their selection. Nevertheless, the data show that in this case, the state digital terrain model 5G (DMR) always shows an average vertical error of 51 cm when comparing two independent technologies (ground measurements and aerial measurements), as can be seen in Figure15. This comparison was carried out as an additional independent verification of the data, and the Czech inspection authority relies primarily on this data when imposing any penalties. This means that a certain margin of error must be allowed for small landfills.

According to the Czech Office of Surveying and Cadastre, the reported mean squared error in open countryside is approximately 18 cm, suggesting that elevation accuracy varies significantly depending on the measurement method and environmental conditions. This discrepancy underscores the need for careful calibration and validation of remote sensing data when used for precise geospatial applications [23].

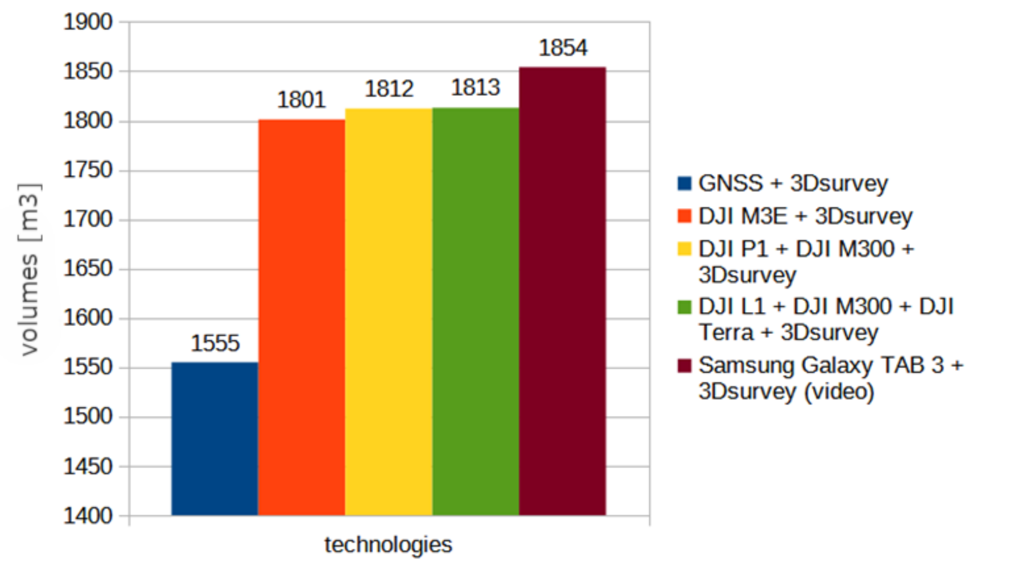

Fig.16 - Comparison of volumes from different technologies

Here it is a very active area, so some surface treatment may have been carried out shortly before the day of the measurement. Another comparison is the results of the volumes calculated by different technologies. The comparison of elevation measurements using GNSS technology and the more precise laser scanning method shows differences in the range of a few centimetres, but for peak measurement points, the deviations can exceed 10 cm. A detailed analysis can be found in the profiles of individual measurement points at the peaks of the surveyed volume (see Figures 17,18).

A key conclusion of this study is that while GNSS technology has certain inaccuracies in determining point positions, especially when tilt-based measurements are used, the primary factor affecting measurement accuracy was not the technology itself but rather the insufficient distribution of measurement points for volume assessment. The author of this study considers the density and placement of points to be the main reason for the observed differences compared to other methods. Moreover, GNSS technology focuses less effectively on volumetric objects than other methods due to its selective nature. Measurement points are chosen directly in the field, which can lead to distortions in the terrain model. For example, when measuring volumetric objects, attention is usually given only to the bottom and top boundaries, which affects data interpretation, as illustrated below.

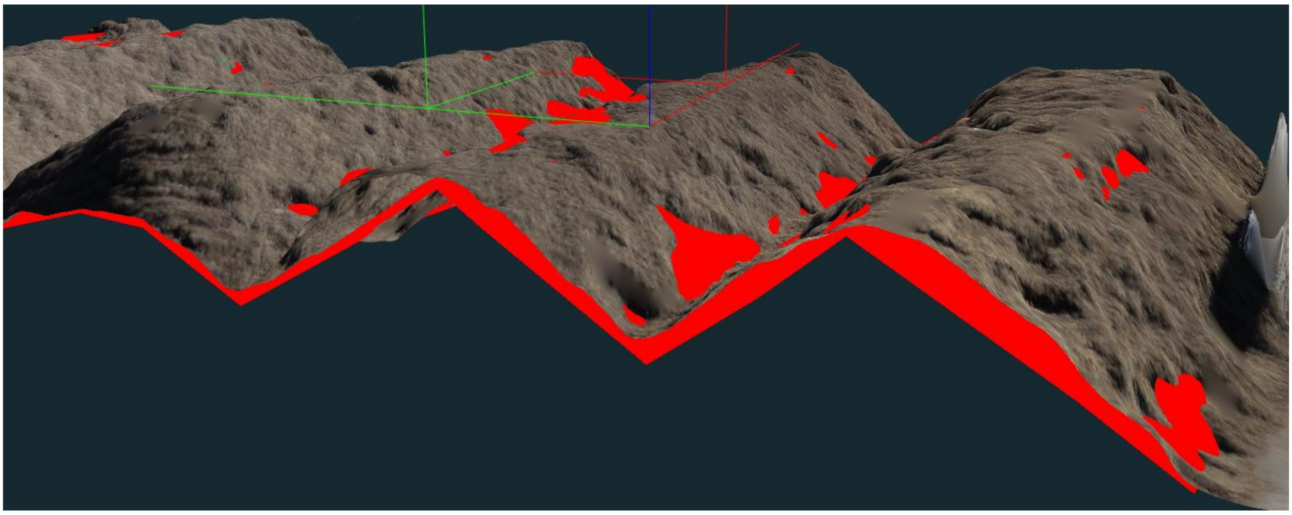

Fig.17-GNSS (red colour) and L1 data comparison, by O. Váňa

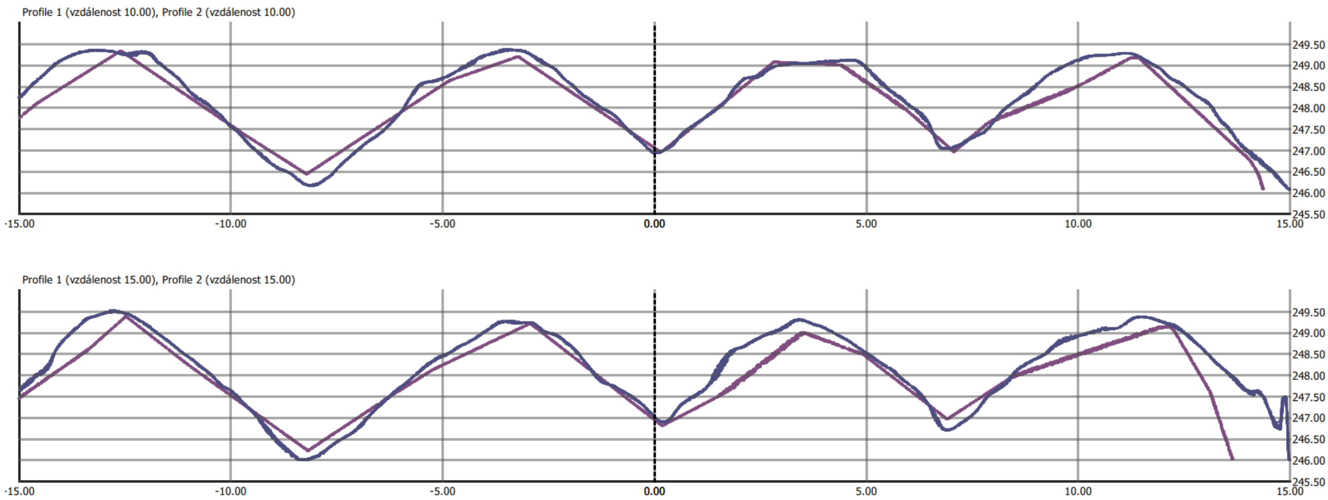

Fig.18 – Cross-sections of the point cloud measured by GNSS (pink colour) and L1 (blue colour) for elevation difference comparison, by O. Váňa

When performing local measurements with GNSS, it is essential to select the points that define the shape of the landfill. If they are selected correctly, the shape and the resulting volume can be used. However, it is not always possible to measure the landfill with such precision.

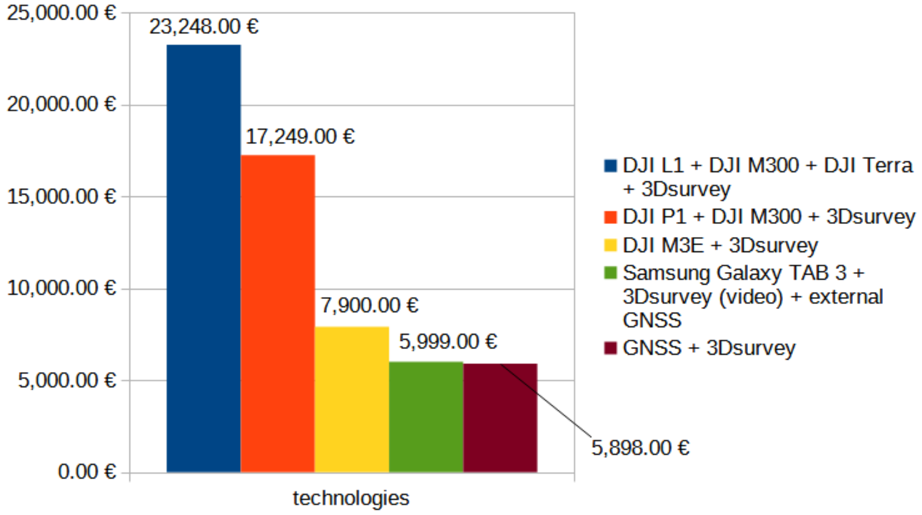

Fig.19 – Comparison of price for used technologies

CONCLUSION

A comparative analysis of GNSS, UAV photogrammetry, UAV laser scanning, and videogrammetry methods was successfully conducted. Additionally, a check measurement was performed to determine if DMR5G could be utilized at this site or if it indicated any terrain alterations. However, the average resulting value of 51 cm suggests that the measured location is an active landfill, which may have been temporarily landscaped on the day of the DMR5G measurement. Despite this, the comparison of the volumes themselves was surprisingly successful.

GNSS measurements stand out significantly. One major drawback of GNSS is the manual data selection. In the field, the surveyor must manually choose measurement points, which can greatly distort the site's perception unless considerable time is spent measuring and selecting points. Despite this, the technology is quite affordable; for instance, the Emlid RS3 is priced at around €3,000 and does not require any additional software to produce outputs in a binding geodetic coordinate system.

Videogrammetry might be the most advantageous method. It is relatively inexpensive as it can be implemented with any Android device paired with an external GNSS receiver, such as the Reach RS3. Although this method yields better results, it still requires manual traversal of the entire measurement area. Additionally, software must be purchased to process the video data.

Drones, such as DJI L1, P1, or M3E, have proven to be highly accurate. However, the main disadvantage is the need for permission to fly over the area. Without permission, other technologies mentioned earlier must be used. The most precise method is likely DJI L1 LiDAR data acquisition, which does not require point cloud calculations based on photographs, unlike the DJI P1 and M3E. However, acquiring the DJI L1 necessitates purchasing a carrier like the Matrice 300/350, DJI Terra for data processing, and software for cubature processing. For the DJI P1, while DJI Terra is not strictly necessary, it still requires additional software for optimal results.

If we have permission to fly in the area and we are looking for the easiest solution for volume mapping without requiring results in the mandatory Czech geodetic system, the most suitable choice including software is the DJI M3E + 3Dsurvey for €7,900. If flying is not an option, the most suitable method is videogrammetry using an Android phone with an external GNSS receiver and 3Dsurvey, totalling €5,999.

A new feature in this field is mapping using LiDAR on iOS Pro and Pro MAX versions, which unfortunately were not available for this measurement. Their advantage lies in the collection of point clouds and, thanks to GNSS, direct output in the binding geodetic system. The future of this study aims to test this technology on a large scale, starting with a comparison of LiDAR data.

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