

APPLICATION OF MOBILE MAPPING SYSTEM FOR A MODERN TOPOGRAPHY

M. Arseni ^a, O. Roman ^{b*}, C. Cucoara ^c, L. P. Georgescu ^a

^a Faculty of Sciences and Environment, “Dunarea de Jos” University of Galati, 800201 Galati, Romania / REXDAN Research Infrastructure, “Dunarea de Jos” University of Galati, 800201 Galati, Romania,
E-mails: maxim.arseni@ugal.ro, lucian.georgescu@ugal.ro

^{b*} REXDAN Research Infrastructure, “Dunarea de Jos” University of Galati, 800201 Galati, Romania / Cross-Border Faculty, “Dunarea de Jos” University of Galati, 800201 Galati, Romania, E-mail: octavian.roman@ugal.ro

^c S.C CarTop S.R.L., 900684 Constanta, Romania, E-mail: cartop_ct@yahoo.com

Received: 10.04.2024 / Accepted: 24.06.2024 / Revised: 03.07.2024 / Available online: 15.12.2024

DOI: 10.2478/jaes-2024-0023

KEYWORDS: mobile mapping system, point cloud, trajectory estimation, laser scanning, topography.

ABSTRACT:

The mobile 3D mapping systems (MMS) and the integration with Geographical Information Systems (GIS) represent an innovative and efficient approach to modern topography. It is recommended and useful for infrastructure analysis and urban planning. This modern technology provides accurate, fast, and detailed data, facilitating well-informed decision-making and contributing to the development of sustainable infrastructure in the 21st century. The purpose of this research was to use a mobile mapping system for land surveying measurement of an urban area, independent of pre-established ground control points. On the other hand, the research is supposed to demonstrate the usefulness of kinematic trajectory, digital imaging, and laser scanning in acquiring, storing, and processing point cloud data. This paper shows an affordable method and a modern scanning instrument used for mobile mapping scanning, to create a georeferenced point cloud (PC). The obtained result has centimetric precision of georeferenced point cloud data, even if the average speed of the car was about 30km/h. The trajectory adjustment with static GNSS measurements increases the accuracy of ground control points (GCPs) up to $\pm 5\text{cm}$ for horizontal positioning and vertical positioning. Although this study was carried out while the system was mounted on a car the result followed the national accuracy requirements for land surveying and cadastre fields. In other words, the mobile mapping system is a faster and cost-effective in time alternative to static laser scanning and it is important to continue to explore and adopt these technological solutions to face the future challenges in the field of urban development and infrastructure.

1. INTRODUCTION

1.1 General Instructions

In modern topography, mobile scanning tools have become an integral part of survey activities, for various fields of activity, from research to business (Puente et al., 2013). These innovative devices, based on advanced computer vision and image processing technologies, provide the user with the ability to quickly and efficiently scan a variety of images, 3D objects, urban areas, or infrastructure areas turning them into an electronic format for further use.

Different topography instruments and methods are used nowadays for land surveying and cadastre fields, such as digital levelling systems, GNSS equipment, static scanners, or mobile scanning systems (Figure 1) (Banescu et al., 2018, 2020).

Mobile mapping systems are becoming an increasingly popular and relevant tool for obtaining accurate and detailed information about the surrounding space. This technology, which uses LiDAR technology to quickly and accurately collect geometric data from objects and their surroundings, provides unique

capabilities for a variety of applications including surveying, construction, architecture, archaeology, robotics, and more (Chiang et al., 2021; Elhashash et al., 2022).

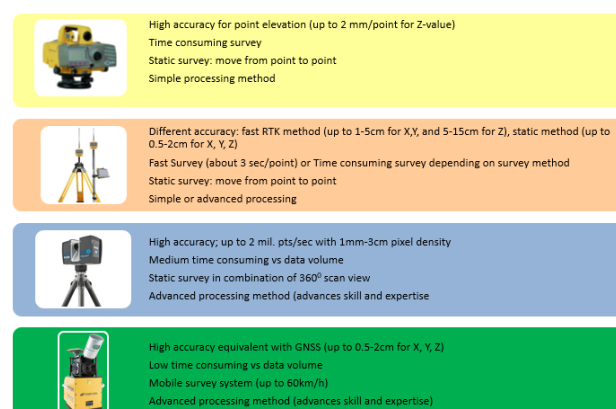


Figure 1. Modern instruments for land surveying measurement and their effectiveness in accuracy point of view

* Corresponding author: Octavian Roman, E-mail: octavian.roman@ugal.ro

On the other hand, the MMS method can be used for the determination of building's flood risk map, by developing a scalable process for facade extraction openings exposed to this hazard. By use of MMS, the facades can be extracted and projected as 2D images for object detection and model generation for flood risk (Feng et al., 2022). Another study of atypical uses of mobile mapping systems was applied for traffic sign identification and segmentation (Qiu et al., 2022).

In our scientific work, we focus on the study of the mobile laser scanning method, its operating principles, technical characteristics, and capabilities. We aim to analyse current trends in the development of this technology, identify its advantages and limitations, and explore the potential for its application in various fields of science and industry.

The purpose of our work is to provide a comprehensive overview of the mobile mapping system (MMS) Topcon IP-S3, consider its capabilities and development prospects, and explore the impact of this technology on modern land surveying. Additionally, we plan to analyse and evaluate the effectiveness and potential for solving specific problems in urban areas.

Through systematization and analyses of surveyed data, as well as through experiments and research, we aim to expand our understanding of mobile laser scanning and offer practical recommendations for its use in various fields of activity.

2. STUDY AREA

The study area was focused on an urban area, where there are different types of relief elevations, infrastructure attributes, some trees, and a lot of urban construction (Figure 2). It is situated in the central part of Romania, between 25°21'30" to 25°23'00" East longitude and 45°45'34.00" to 45°46'26" North latitude.



Figure 2. The study area: Vladeni village (Brasov County, Romania)

The study area was chosen at the request of the CarTop S.R.L. beneficiary, in the idea of measuring different relief options. Factors such as surface roughness, dense vegetation in some areas, and the presence of obstacles like buildings, small bridges, or trees were necessary to assess the performance of MMS.

3. MATERIALS AND METHODS

To achieve the main purpose of this study modern topography MMS equipment from Topcon, namely Topcon IP-S3 was used. It is a sophisticated MMS used to collect geospatial data and create detailed maps of the environment while in motion. The IP-

S3 scanning system consists of various sensors, instruments, and software integrated into a mobile platform, in our case a 4x4 SUV vehicle (Figure 3). The main important component of IP-S3 MMS can capture different types of data simultaneously.



Figure 3. The mounting MMS on a 4x4 SUV, wheel encoder, and cable connections to the timing box inside the vehicle

3.1 System configuration for MMS Topcon IP-S3

3.1.1 LiDAR (Light Detection and Ranging): The IP-S3 instrument has a Velodyne HDL 32 LiDAR sensor, which emits a rate of 700,000 laser pulses per second and measures their reflection, to capture a 3D point cloud at a maximum of 100m distance out at 100% reflectivity (Figure 4 a) (Chan et al., 2013; Jozkow et al., 2017). This data is used further for terrain modeling, feature extraction, or infrastructure mapping in our case. The 32 internal lasers in the system rotate continuously and cover the entire 360 degrees, each emitting from a slightly different angle (Alsadik, 2021). This design enables the system to capture a dense point cloud with minimal gaps, eliminating the need for multiple scanners. The full 360-degree coverage and multiple viewing angles help to reduce blind spots or dead angles, providing comprehensive data for the system.

3.1.2 GNSS antenna (GPS and GLONASS): The IP-S3 positioning system integrates a Topcon PG-S1 GNSS antenna with a 10hz data update and 226 channels for decrypting (Figure 4 b) (Allred et al., 2018). It helps to provide precise location information, enabling accurate georeferencing of the collected data in the post-processing step.

3.1.3 Spherical Camera: A Ladybug spherical camera for image data capture is used. The CCD camera of IP-S3 features six lenses that capture high-resolution, 360-degree spherical images, with a 30-megapixel resolution which facilitates easy identification of distinctive features (Figure 4 c) (Lichti et al., 2020).

3.1.4 IMU (Inertial Measurement Unit): The IMU sensor integrated into the main cube unit (Figure 4 d) helps to measure the system's orientation and motion with a 1°/hr gyro stability. At the same time acceleration with a 7.5 mg stability and angular

velocity are stored, allowing for correction of sensor data and the development of stable mapping outputs.

3.1.5 Wheel encoder: The wheel encoder mounted on the wheel vehicle (Figure 4 e) is a piece of equipment utilized to gauge the spinning motion of the wheel. The 2500 pulse rate

acquire picks up alterations in position or rotation which produces electrical signals that correspond to these modifications. The wheel encoder works in tandem with the PG-S1 antenna and IMU system to deliver precise 3D vehicle positioning, even in areas with obstructions such as buildings, bridges, or tree lines that can block satellite signals.

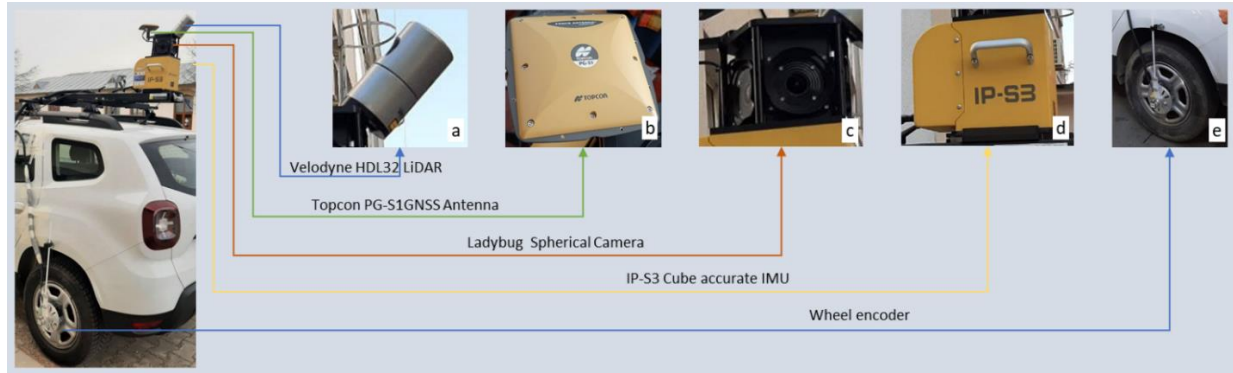


Figure 4. The Topcon IP-S3 outside of vehicle system configuration

3.2 General survey method

The survey with Topcon IP-S3 MMS involves important steps to ensure accurate data collection. The main key steps are:

- 1) plan the scanning paths, considering the terrain, obstacles, and required coverage area
- 2) the initial calibration of the instrument, to ensure the initialize of the IMU sensor
- 3) data acquisition with a constant vehicle velocity
- 4) some time to review the scanned data in real-time to identify anomalies, errors, or missing areas
- 5) data processing involves applying filters, noise reduction, and other post-processing methods to ensure the final quality of data

- 6) analysis and interpretation of the processed data to generate 3D models, digital terrain models, or other formats for visualization.

The total length of the scanned path was 12 km. The maximum speed of the vehicle was 48.6 km/h. To produce georeferenced point cloud data all data collected from the system sensors come through a Kalman filter algorithm. These filters consist of a series of mathematical equations using a series of surveyed items over time, to produce an estimation of past, present, and future states. The horizontal and vertical coordinates of each point from the 3D point cloud are obtained according to equation 1 (Bury et al., 2016; Maslikhova et al., 2020):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^l = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_r^l + Rb_b^l(r, p, \gamma) \cdot \left(\rho \cdot R_s^b(\omega, \varphi, k) \cdot \begin{bmatrix} \cos \gamma \cdot \sin \theta \\ \cos \gamma \cdot \cos \theta \\ \sin \gamma \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_s^b - \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_r^b \right) \quad (1)$$

4. RESULTS AND DISCUSSION

4.1 Trajectory adjustment

The accuracy of the trajectory or path of the mobile survey is a vital step in the data processing workflow of IP-S3 MMS. This process, known as trajectory adjustment, plays a crucial role in improving the accuracy and reliability of the collected data. Figure 5 shows the approximation of the mean trajectory, given by the differences in motion registered by the wheel encoder. Additionally, by aligning the trajectory with ground truth GNSS base station corrections, trajectory adjustment improves the overall accuracy of the collected point cloud data (Gressin et al., 2012; Schaer & Vallet, 2016).

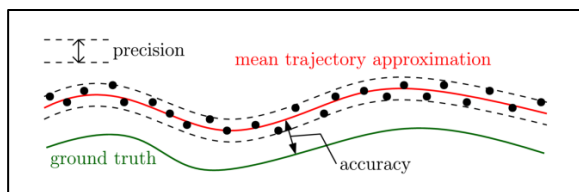


Figure 5. Trajectory adjustment step

The results show that trajectory adjustment ensures smooth transitions between individual scan lines or segments, minimizing discontinuities or artifacts in the point cloud data (Figure 6).

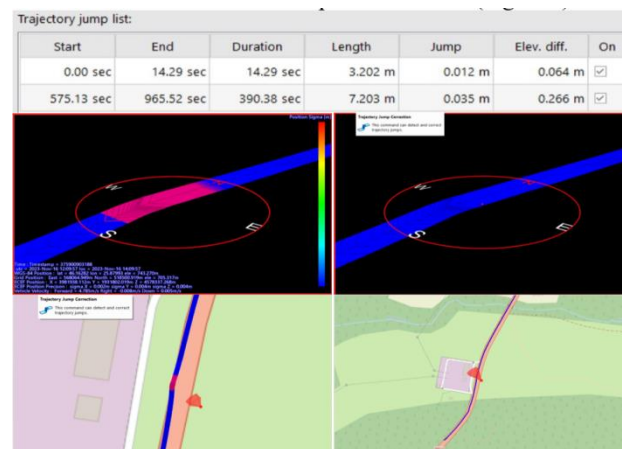


Figure 6. 3D MMS trajectory estimation and comparison of results after trajectory jump correction

4.2 GNSS static survey

The coordinate of the Vladeni 001 and 002 base points was measured by the static GNSS method. Two receivers were installed in different locations. The receivers are mounted on a wooden tripod. A wooden tripod was used, as it is not influenced by temperature changes, which change from one period of time to another. After mounting the receiver on the base, and the base on the tripod, their position on the tripod is adjusted and fixed on the observation point. The leveling was initially approximate with the help of the front of the tripod legs and spherical level. Next, the screws of the base are used and with the help of the toric level, the leveling of the equipment was finished. The final leveling is done, obtaining a maximum positioning accuracy on the point of sight of observation ($\pm 0.5 - 1$ mm). The base station point was marked with Feno survey markers (Figure 7).



Figure 7. The GNSS mount on the base point (left image) and marking the points on the ground using Feno type survey marker

The results from GNSS static survey results are very important for point cloud georeferencing and smoothing. At the same time, GNSS static records were used to accurately determine the positions of GCPs in the survey area. On the entire surveyed area was marked 2 GCPs, for the improvement of georeferenced of the point cloud data. Figure 8 shows the differences between satellite time records and GCPs GNSS records.

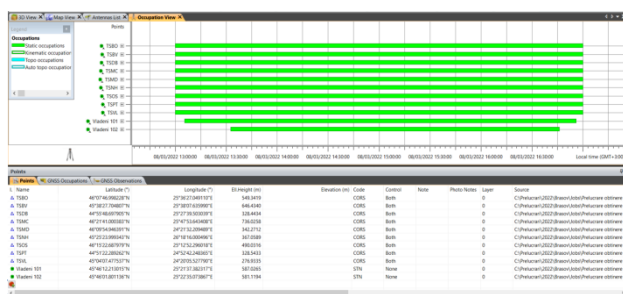


Figure 8. The satellite time records of fixed reference stations which cover entirely the GNSS static records

To adjust the Vladeni 001 and Vladeni 002 CGPs, 8 fixed reference station records were used. The cube-time spatial representation shows a uniform distribution of fixed reference stations (Figure 9).

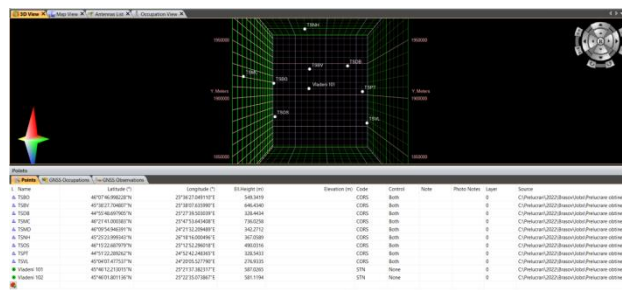


Figure 9. The cube-time spatial representation of the positioning of fixed reference station versus Vladeni 001 ground control point.

4.3 Smoothing point cloud

To obtain a flat surface it is important to apply a smooth cloud filter. This filter helps to eliminate the noise points located near each flat surface. In the post-process step, when we applied the smooth filter with a 5 mm sigma preserve, the data became more flat (Figure 10). The edge sharpness was set to high.

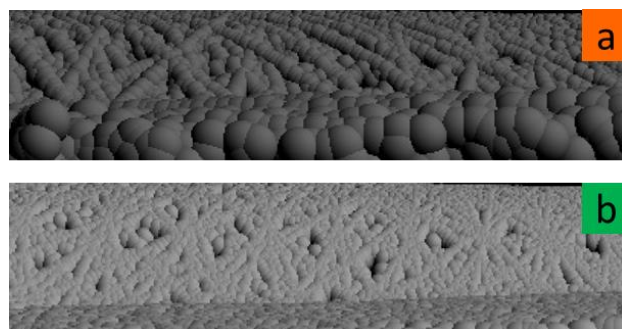


Figure 10. Example of point cloud before (a) and after (b) smooth filter is applied

4.4 Point cloud representation

The measurements were processed using the MAGNET Collage v2.8 software, which includes 2 modules. The first module helps to process the trajectory (Azam et al., 2023). The second module is for the processing of LiDAR measurements and the images taken by the 360° camera to obtain the cloud of points in the three dimensions X, Y, and Z. The result of the processing consists of the alignment of the cloud points according to the trajectory and its adjustment using the post-processed GNSS records collected by the static method (Figure 11) (Ma et al., 2018).

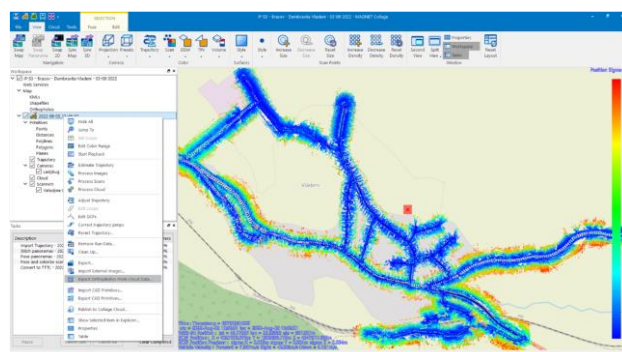


Figure 11. The results of the post-process step which includes the entire scanned area

After the post-processing steps which involve different adjustments and filters the final results can be visualized in different modes (Figure 12). The results show that the measurements were carried out at about 70m on both sides. (Figure 10). This is the normal distance reflectance of the LiDAR sensor.

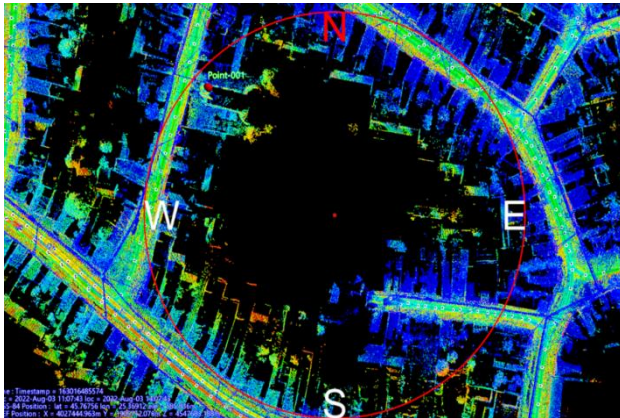


Figure 12. The side scan distance coverage in normal reflectivity condition

The point cloud elevation geospatial result helps us to identify the buildings, trees, roads, or some specific environmental elements. The blue to green colour (Figure 13) represents lower to highest elevation entities. The differentiation of elevation zones or intervals, in this research, was useful for analysing the elevation variations across the landscape. Dividing the elevation range into discrete intervals and assigning a unique colour to each interval, gives the possibility to identify areas with similar elevation characteristics.

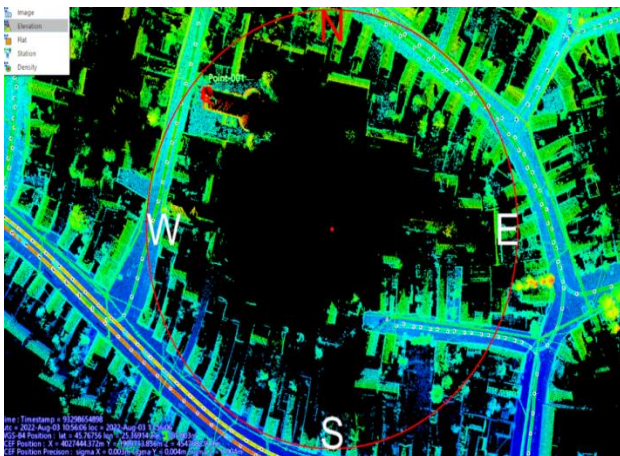


Figure 13. Elevation representation of the point cloud

By analysing the elevation representation of the point cloud data it was identified the highest point, which represents a church building (Point 001). The height measuring tool helps us to measure very fast the elevation of the mentioned object. So, the slant distance from the ground to the highest point of the church was 35.926m, on the other hand, the vertical distance was 35.393m (Figure 14).



Figure 14. The 3D point cloud image of the church and automatic height measurements of objects

To evaluate the spatial distribution of the points within the point cloud and the detail and coverage provided by the dataset it was calculated the density at 1m grid cell. The results show an average of 1028 points at a 1 m grid after the final process of point cloud data (Figure 15). By examining the elevation histogram (Figure 16) the average value of the point elevation (Black Sea “zero Constanta 1975” reference Datum) is 541.99m, and more than 80% of scanned points are near these values.

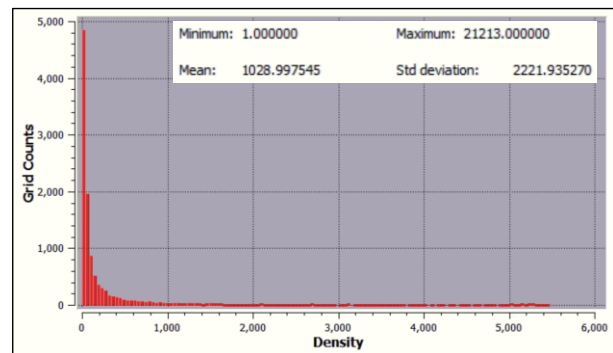


Figure 15. The density of cloud point at 1m grid cell

The maximum elevation of the surveyed point with MMS was 554.93m. The spread around the central tendency for elevation value was very high with a 1.84m standard deviation.

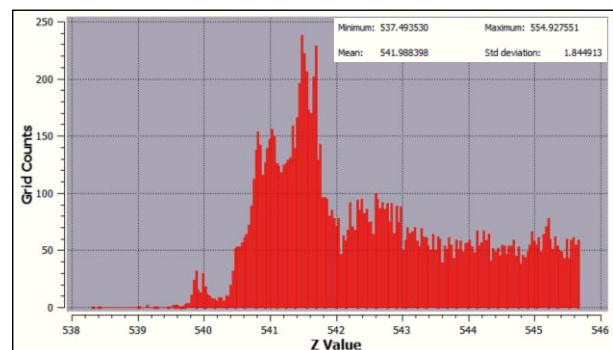


Figure 16. The skewness and kurtosis disproportionally in the elevation values data distribution.

To assess the quality of the surveyed data, by using the MMS, 30 ground control points (GCPs) were measured by the classic GNSS method (rapid static method) (Figure 17). The knowledge of the error between GCPs and scanned points shows the propagation through the entire datasets.

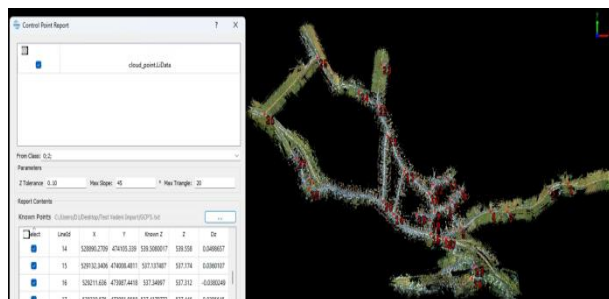


Figure 17. The GCP's marks and input parameters for quality assessment

Understanding error propagation is essential for assessing the overall reliability of the dataset. The Z coordinate of GCP's points was compared with the z-value from obtained point cloud data. The error determination assumes that the surveyed GPSs are the reference points. So, the tolerance of the z-value was set to 0.10m. All points that are outside the 45-degree angle were excluded from the comparison calculation.

The results showed that the standard deviation for the elevation error was 0.031m. The average error was 0.0023m. The propagation of this error is minimal for the entire data set. These very low-value errors (Figure 18) show that the scan can be adjusted and processed only on the Vladeni base points 001 and 002.

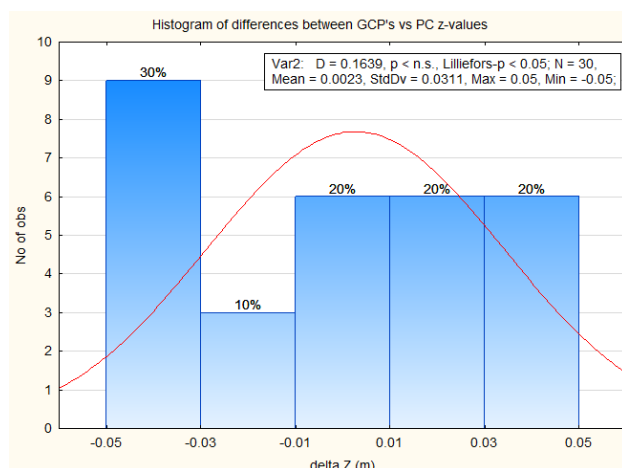


Figure 18. Distribution plot of differences between GCP's and PC z-values

5. CONCLUSION

In conclusion, we can mention that the use of MMS represents an advantage in data collection for modern topography. MMS Topcon IP-S3 equipment is a quick solution and helps to collect a large volume of topographical data. This system is mobile, portable, and can be mounted on any car by small adaptations. This mobility allows us to cover large areas regardless of the elevation conditions of the land.

Regardless of the driving speed of the vehicle (maximum allowed 60km/h), the precision of the coordinates is better than +/- 5 cm for X, Y, Z. The minimum difference between GCP'S and PC z-value was 0.0015 m, on the other hand, the maximum difference was 0.050 m. These values are far above the limit imposed by the National Agency of Cadastre and Land Registration from Romania. By using the Topcon IP-S3 MMS we have sufficient

data coverage with a very good resolution and maximum details of the recorded point cloud.

Through the cost-benefit analysis (Table 1), it can be seen that in the case of an MMS-type scan, the number of experts and time consumed for surveying is significantly reduced. At the same time, the use of the mobile scanner reduces the risk for experts in the field, because data can be collected without necessary to access restricted areas or very dangerous/sloped terrain.

The MMS for modern topography is useful and provides information in real time, through the direct visualization of the point cloud. It offers various information in the form of visible images, point clouds, and GNSS recordings. The post-processed data can be used in various topographical applications, but also for other related fields: environmental parameters monitoring, agriculture and forestry, road safety, architecture, and urban cartography.

Criteria	Mobile Mapping System Survey	Conventional Survey
No. of experts (field survey)	2	Min. 4
Time for surveying	16 hours including the trip Galati - Vladeni	120 hours (more than 3 weeks of survey)
Time for data extraction	2 hours from MMS + 2 hours from GNSS = 4 hours	<1 hour
Time for processing	12 hours for MMS data + 3 hours for GNSS static survey = 15 hours	
Time for choosing points of interest and drawing up plans/profiles	3 hours of classification of point cloud data + 2 hours of automatically digitizing + 16 hours of manual digitizing + 24 hours of drawing up plans/profiles	80 hours (point by point)
Total consumption time	80 hours	201 hour
Density/Data volume	more than 200pts/sq.m.	less than 1 pt./sq.m
Price of equipment	~ 400.000€	~ 40.000€
Total cost of surveying and post-processing	~ 3000€	~ 10000€

Table 1. Vladeni village study case – cost-benefit analysis

However, even though the use of the MMS topographic surveying technique has countless advantages, there are also several disadvantages to mention (Table 2).

ADVANTAGES	DISADVANTAGES
High efficiency: Mobile mapping systems can rapidly collect data over large areas	Cost: Mobile mapping systems, especially those equipped with LiDAR and high-resolution cameras, are expensive to purchase
Accuracy: Modern MMS use advanced technologies like GPS, LiDAR, and cameras to capture highly accurate geospatial data	Data storage and processing: The big volume of data generated by mobile mapping systems, especially LiDAR and high-resolution imagery, can be challenging to store
Safety: MMS can be used to survey and assess potentially hazardous or hard-to-reach areas	Sensor occlusion: Mobile mapping systems mounted on vehicles may have limited visibility of objects obstructed by other vehicles, buildings, or vegetation

Real-time data: Topcon IP-S3 MMS can provide real-time data	Environmental impact: The energy consumption and potential emissions associated with mobile mapping vehicles can have an environmental impact
Data integration: Mobile mapping systems can collect various types of data simultaneously, such as imagery, LiDAR point clouds, and GPS coordinates.	Complexity and technical expertise: The use of MMMS requires well-trained experts, with advanced expertise in the operation of the equipment, as well as in the processing and analysis of point cloud data

Table 2. The main general applicable advantages and disadvantages criteria of using MMS technique

The advantages and disadvantages are presented to help the researcher or expert who intends to make projects for land surveying, to choose the convenient method depending on budget, staff number, or the extent of the survey area.

6. ACKNOWLEDGEMENTS

The present paper uses the REXDAN Research Infrastructure resources, created by the project An Integrated System for the Complex Environmental Research and Monitoring in the Danube River Area, REXDAN, SMIS code 127065, co-financed by the European Regional Development Fund through the Competitiveness Operational Programme 2014-2020, contract no. 309/10.07.2021.

References

Allred, B., Wishart, D., Martinez, L., Schomberg, H., Mirsky, S., Meyers, G., Elliott, J., & Charyton, C. (2018). Delineation of agricultural drainage pipe patterns using ground penetrating radar integrated with a real-time kinematic global navigation satellite system. *Agriculture*, 8(11), 167.

Alsadik, B. (2021). Performance assessment of mobile laser scanning systems using Velodyne Hdl-32e. *Surveying and Geospatial Engineering Journal*, 1(1), 28–33. <https://doi.org/10.38094/sgej116>.

Azam, A., Alshehri, A. H., Alharthai, M., El-Banna, M. M., Yosri, A. M., & Beshr, A. A. (2023). Applications of Terrestrial Laser Scanner in Detecting Pavement Surface Defects. *Processes*, 11(5), 1370.

Banescu, A., Arseni, M., Georgescu, L. P., Rusu, E., & Iticescu, C. (2020). Evaluation of different simulation methods for analyzing flood scenarios in the Danube Delta. *Applied Sciences*, 10(23), 8327.

Banescu, A., Georgescu, L. P., Rusu, E., & Iticescu, C. (2018). Use of GIS technology to support the navigation on the Danube River. *International Conference on Traffic and Transport Engineering ICTTE Belgrade*, 160–168.

Bury, G., Sosnica, K., Borkowski, A., & Trznadel, L. (2016). Development of a mobile platform for interior laser scanning based on the terrestrial phase scanner. *International Association*

of Geodesy (IAG), Commission 4 Symposium, Polland, Wroklow.

Chan, T. O., Lichti, D. D., & Belton, D. (2013). Temporal Analysis and Automatic Calibration of the Velodyne HDL-32E LiDAR System. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, II-5-W2, 61–66. <https://doi.org/10.5194/isprsannals-II-5-W2-61-2013>.

Chiang, K. W., Tsai, G.-J., & Zeng, J. C. (2021). Mobile Mapping Technologies. In W. Shi, M. F. Goodchild, M. Batty, M.-P. Kwan, & A. Zhang (Eds.), *Urban Informatics* (pp. 439–465). Springer. https://doi.org/10.1007/978-981-15-8983-6_25.

Elhashash, M., Albanwan, H., & Qin, R. (2022). A Review of Mobile Mapping Systems: From Sensors to Applications. *Sensors*, 22(11), Article 11. <https://doi.org/10.3390/s22114262>.

Feng, Y., Xiao, Q., Brenner, C., Peche, A., Yang, J., Feuerhake, U., & Sester, M. (2022). Determination of building flood risk maps from LiDAR mobile mapping data. *Computers, Environment and Urban Systems*, 93, 101759. <https://doi.org/10.1016/j.compenvurbsys.2022.101759>.

Gressin, A., Cannelle, B., Mallet, C., & Papelard, J.-P. (2012). Trajectory-based registration of 3D LiDAR point clouds acquired with a mobile mapping system. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, I-3, 117–122. <https://doi.org/10.5194/isprsannals-I-3-117-2012>.

Jozkow, G., Wiecezorek, P., Karpina, M., Walicka, A., & Borkowski, A. (2017). Performance evaluation of UAS equipped with Velodyne HDL-32e LiDAR sensor. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2-W6, 171–177. <https://doi.org/10.5194/isprs-archives-XLII-2-W6-171-2017>.

Lichti, D. D., Jarron, D., Tredoux, W., Shahbazi, M., & Radovanovic, R. (2020). Geometric modelling and calibration of a spherical camera imaging system. *The Photogrammetric Record*, 35(170), 123–142. <https://doi.org/10.1111/phor.12315>.

Ma, L., Li, Y., Li, J., Wang, C., Wang, R., & Chapman, M. A. (2018). Mobile laser scanned point-clouds for road object detection and extraction: A review. *Remote Sensing*, 10(10), 1531.

Maslikhova, L. I., Hahulina, N. B., Sambulov, N. I., & Akimova, S. V. (2020). Analysis and Comparison of Technologies of Survey of Buildings and Structures for the Purpose of Obtaining a 3D Model. *IOP Conference Series: Materials Science and Engineering*, 753(3), 032061. <https://doi.org/10.1088/1757-899X/753/3/032061>.

Puente, I., González-Jorge, H., Martínez-Sánchez, J., & Arias, P. (2013). Review of mobile mapping and surveying technologies. *Measurement*, 46(7), 2127–2145. <https://doi.org/10.1016/j.measurement.2013.03.006>.

Qiu, Z., Martínez-Sánchez, J., Brea, V. M., López, P., & Arias, P. (2022). Low-cost mobile mapping system solution for traffic sign segmentation using Azure Kinect. *International Journal of Applied Earth Observation and Geoinformation*, 112, 102895. <https://doi.org/10.1016/j.jag.2022.102895>.

Schaer, P., & Vallet, J. (2016). Trajectory adjustment of mobile laser scan data in GPS denied environments. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-3-W4, 61–64.
<https://doi.org/10.5194/isprs-archives-XL-3-W4-61-2016>.