



GEODETTIC SURVEYING OF MOTORWAYS USING MOBILE LIDAR SYSTEMS FOR PAVEMENT REHABILITATION AND ROAD DATABASE UPDATING

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Abstract

This paper presents the procedure of geodetic surveying of motorway routes using modern GNSS technologies and mobile LiDAR scanning with the aim of developing a detailed horizontal and vertical pavement model and updating the Road Database. The process of establishing the geodetic control network, field surveying, data processing, quality control and structuring of geospatial data in accordance with the Project Assignment requirements is described.

Keywords: geodetic networks, GNSS, LiDAR, road database

1 Introduction

The maintenance and improvement of road infrastructure are essential for a safe and efficient transport system, particularly on motorways as key transport corridors in Croatia. Effective pavement rehabilitation planning requires accurate and reliable geodetic data for assessing existing conditions and defining optimal interventions. This paper focuses on the geodetic surveying of the main routes of motorways A1, A6 and A7, with particular emphasis on the methodology of establishing the geodetic control network, surveying cross-sections using a mobile scanner and processing and organizing data for the purposes of pavement rehabilitation and updating the Road Database of Hrvatske autoceste d.o.o. Modern geodetic procedures, particularly the application of GNSS technologies, precise geodetic networks and mobile laser scanning, enable rapid and highly accurate collection of large-scale spatial data [2, 3]. The integration of such data into geospatial databases represents the foundation for efficient road infrastructure management. In recent years, significant advancements have been achieved in the field of geodetic data acquisition for pavement modelling, particularly through the integration of GNSS technologies, mobile LiDAR systems, and inertial measurement units (IMU). Mobile laser scanning enables rapid, high-density, and highly accurate spatial data collection over large infrastructure networks, making it especially suitable for motorway-scale projects. Compared to traditional geodetic surveying methods, such as total station-based profiling, mobile LiDAR significantly reduces field time while maintaining centimeter-level accuracy [1, 2].

2 Geodetic control network

The project documentation defined the establishment of a geodetic control network with three types of geodetic points: main points every 25–35 km, base points every 5 km and auxiliary points every 150 meters [3]. The required network accuracy is ± 15 mm in position and ± 10 mm in height, while the relative accuracy of profile points must be ± 10 mm in position and ± 6 mm in height.

2.1 Establishment of the geodetic control network

Main points were stabilized using concrete blocks measuring 100×20×20 cm. Base points were stabilized with 5 cm bolts and auxiliary points with flat-head bolts. The density of auxiliary points increased at all tunnels by placing three points before and after each tunnel, while inside tunnels points were installed every 75 meters. On the opposite side of the road, points were placed at a maximum spacing of 1 km. A total of 2, 339 auxiliary points were marked. All auxiliary points were numbered and marked with two white squares measuring 20×20 cm and painted with road marking paint to ensure automatic recognition during LiDAR measurements (figure 1). Wherever possible, auxiliary points were placed in the emergency lane, while in locations without an emergency lane, points were installed along the edge of the driving lane.



Figure 1 Templates for marking points and example of point marking

2.2 Geodetic measurements

The positions of the main points were determined using the GPPS positioning service of CROPOS, with vector observation sessions toward at least three CROPOS CORS reference stations, conducted twice for 4 hours each under different satellite constellations. They were installed at intervals of 25–35 km. The positions of base points were determined by static GNSS observations with observation durations in accordance with the rules for dual-frequency GNSS receivers. Two observation sessions were performed for each point under different satellite constellations. They were installed at intervals of 5 km. Auxiliary points were observed using the CROPOS VPPS positioning service with a minimum of three sessions of 30 epochs each in order to obtain approximate coordinates.

Using total stations with 0.5" accuracy, the geodetic control network was measured by the free station method, following the principle that at each station two points ahead and two points behind the instrument station were measured. In this way, each auxiliary point was measured at least four times (twice from ahead and twice from behind the instrument station), ensuring a sufficient number of redundant measurements for network adjustment. All geodetic measurements were adjusted by combining GPS measurements and terrestrial measurements obtained by total stations using the least squares method in the specialized geodetic network adjustment software Eupalinos.

An exceptional network accuracy of less than 6 mm in both horizontal and vertical components was achieved for all points along a total of 200 km of motorway, thereby fulfilling the primary requirement of the geodetic network defined in the project assignment.

3 Mobile LiDAR measurements

For mobile LiDAR measurements, the Riegl VUX-1HA device with a panoramic camera was selected. The system is mounted on the roof of a vehicle and is capable of measuring 250 profiles per second. Such measurement density enables obtaining a profile every 5 cm at a driving speed of 50 km/h. Measurements of all 200 km of motorway were completed in two days with an average measurement speed of approximately 60 km/h. To avoid traffic interference, measurements began at around 6 a.m. on both days, when motorway traffic is lighter than usual. During measurements, two escort vehicles accompanied the survey vehicle, while a vehicle with activated rotating warning lights drove ahead (figure 2). For data processing purposes, six GPS devices continuously recorded data during LiDAR measurements. The devices were activated 30 minutes before the start of LiDAR surveying and stopped 30 minutes after completion.



Figure 2 Mobile LiDAR measurements on motorway A7

4 Data processing

Data from GNSS receivers, the IMU system, and control points were used to adjust the collected LiDAR data. The result was a set of three-dimensional XYZ points (figure 3), based on which a terrain model was created.



Figure 3 Motorway section loaded in Global Mapper

The collected data were processed in the software package Global Mapper, from which coordinates and elevations of points in cross-sections every 10 m and at all characteristic points were obtained. Points in cross-sections were constructed:

- along the left pavement edge
- along the edge of the overtaking lane (right edge of the white line)
- at the midpoint between the overtaking and driving lanes (center of the white line)
- along the edge of the driving lane (left edge of the white line)
- along the right pavement edge (right emergency lane).

The following elements were extracted from LiDAR data:

- polygonal elements (driving lane, overtaking lane, emergency lane, edge strip, etc.)
- linear elements (horizontal road markings, guardrails, and noise barriers)
- point elements (kilometer markers and horizontal road markings).

For each element, quality control was performed in AutoCAD MapClean to eliminate duplicates, objects shorter than 1 cm, and “invisible” objects. In QGIS, topological control and geometry checks (Check Geometries) were performed to eliminate possible polygon gaps or overlaps. All obtained data were divided into network elements in accordance with the rules of the HAC database. In this way, smaller segments were created and uploaded into the HAC database by the company IGEA and merged with the existing motorway data.

5 Conclusion

It can be concluded that the application of modern geodetic methods, particularly GNSS technology and mobile LiDAR scanning, enables rapid, efficient, and highly accurate collection of spatial data on large infrastructure systems such as motorways A1, A6, and A7. The establishment of a stable and precise geodetic control network, combined with GNSS and terrestrial measurements, ensured a high level of accuracy and reliability of the collected data. Mobile LiDAR surveying proved to be an extremely efficient method for detailed data acquisition, enabling the creation of a high-resolution three-dimensional pavement model with significant time savings and minimal traffic disruption. The integration of GNSS, IMU, and LiDAR data provides a reliable basis for pavement analysis, rehabilitation planning, and long-term infrastructure management through the HAC database. Although mobile LiDAR surveying has proven to be extremely efficient for large-scale and detailed data acquisition, it does not fully replace classical geodetic methods. The establishment of a precise geodetic control network remains essential to ensure absolute positional accuracy and reliability of the collected data. Mobile LiDAR systems depend on GNSS signal availability and IMU stability, which may be limited in challenging environments such as tunnels, dense vegetation, or urban canyons. Therefore, an integrated approach combining mobile LiDAR with conventional geodetic measurements, such as total station observations and GNSS control networks, is recommended to achieve optimal results in terms of accuracy, completeness, and reliability.

References

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