Journal scientific and applied research, vol. 29, 2025
International Journal

ISSN 1314-6289 (Print)
ISSN 2815-4622 (Online)

Original Contribution

INTEGRATION OF GNSS AND LASER SCANNING FOR IMPROVING THE ACCURACY OF LARGE-SCALE GEODETIC MAPS

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ABSTRACT: *This paper examines the integration of Global Navigation Satellite Systems (GNSS) and Terrestrial Laser Scanning (TLS) as an effective approach to enhance both the accuracy and spatial detail of geodetic measurements. The principles of each technology are presented, along with the advantages of their combined application in georeferencing, 3D modeling, and large-scale mapping.*

KEY WORDS: *GNSS, TLS, Integrated geodetic technologies, Laser scanning, 3D Modeling, Georeferencing, Large-scale mapping.*

1. Introduction

Contemporary geodesy is marked by the rapid advancement of innovative technologies that are transforming the way spatial data are collected, processed, and analyzed. Among these technologies, Global Navigation Satellite Systems (GNSS) and Terrestrial Laser Scanning (TLS) play a particularly significant role. Their combined use not only enhances measurement accuracy but also provides a more comprehensive and detailed representation of spatial information.

In recent years, a clear trend has emerged toward the integration of various geodetic technologies into unified systems for data acquisition and analysis. Such integration has the potential to significantly improve the accuracy and reliability of large-scale geodetic mapping while reducing the time and effort required for fieldwork [1].

2. Principles and Methods of GNSS and Laser Scanning

- Global Navigation Satellite Systems (GNSS) encompass the global constellations GPS (USA), GLONASS (Russia), Galileo (EU), and BeiDou (China), which provide continuous determination of spatial coordinates by measuring code and carrier-phase differences from multiple satellites. The resulting observations allow the computation of precise positions within global reference frames such as WGS84 or ITRF, which are fundamental for modern geodetic operations [2].

GNSS receivers used in geodesy apply advanced algorithms to correct for ionospheric and tropospheric delays, orbital errors, and multipath effects. In static mode, positioning accuracy can reach a few millimeters, while in kinematic modes such as RTK (Real-Time Kinematic) or PPP (Precise Point Positioning), centimeter-level accuracy is achievable in real time [2]. These capabilities make GNSS an essential tool for establishing geodetic control networks, monitoring engineering structures, and providing coordinate reference frameworks for other spatial data systems.

➢ Terrestrial Laser Scanning (TLS) is a technology based on measuring the time-of-flight or phase shift of a reflected laser pulse from object surfaces. Through this process, a three-dimensional point cloud is generated, where each point is defined by its coordinates (X, Y, Z) and often includes intensity or RGB values [9].

Modern TLS systems are capable of capturing millions of points per second, ensuring exceptional geometric detail for architectural structures, infrastructure, terrain, and natural features. The primary stages of TLS data processing include:

- Registration of individual scans (using reflective targets or cloud-to-cloud alignment);
- Georeferencing, i.e., transformation into a global coordinate system;
- Filtering and data optimization to remove noise and outliers;
- Modeling and analysis, including the generation of digital terrain and surface models (DTM/DSM) and deformation monitoring.

TLS enables deformation and structural monitoring with millimeter-level precision, making it particularly valuable for engineering and geodetic applications [10].

3. Integration of GNSS and TLS Technologies

The combined application of Global Navigation Satellite Systems (GNSS) and Terrestrial Laser Scanning (TLS) represents an integrated methodological approach, achieving a synergy between absolute coordinate accuracy and high spatial resolution. This integration enables both geodetic precision and geometric detail, which are essential for contemporary tasks in geodesy, cartography, and geoinformation technologies.

GNSS provides a reference coordinate framework to which TLS observations are anchored. Consequently, point clouds generated through laser scanning can be georeferenced within global or national coordinate systems and used in conjunction with other spatial data sources. This process eliminates local systematic offsets between individual scans and allows their integration into a unified geospatial environment.

Simultaneously, the use of control points determined through high-precision GNSS measurements enhances the metrological reliability of TLS results. This procedure ensures compatibility among different spatial data sources, such as orthophotos, cadastral and engineering datasets, and airborne LiDAR measurements. As a result, a homogeneous coordinate foundation is established, enabling accurate spatial analysis and object modeling.

In recent years, the application of direct georeferencing has become increasingly widespread, where the position and orientation of the laser scanner are determined in real time through the combined use of a GNSS antenna and an Inertial Measurement Unit (IMU). This approach eliminates the need for ground control points and significantly improves the operational efficiency of field surveys, particularly in inaccessible or extensive areas. Integrated GNSS–TLS systems are widely employed in large-scale mapping, three-dimensional (3D) modeling of urban environments, deformation monitoring of engineering structures, and the creation of digital terrain and surface models (DTM/DSM). By combining the global coordinate reliability of satellite technologies with the high local detail of laser scanning, a qualitatively new level of accuracy and information richness is achieved in geodetic research and spatial modeling [11].

The use of unmanned aerial vehicles (UAVs) in combination with GNSS and terrestrial laser scanning can further accelerate the production of high-detail cadastral maps [8]. Modern software platforms, such as Leica Cyclone and Trimble RealWorks, now offer automated solutions for the integration and analysis of combined datasets [3].

This integrated approach saves time and resources, reduces the risk of human errors, and allows for higher compatibility among different spatial data sources.

4. Accuracy Analysis

The accuracy of combined GNSS–TLS measurements depends on multiple factors, including equipment calibration, coordinate system synchronization, and data processing methodology. With well-organized procedures, overall errors below 1 cm can be achieved in large-scale surveys [4].

GNSS provides the primary coordinate framework, while TLS delivers exceptional local precision. The integration of these technologies enables spatial homogeneity and eliminates systematic distortions.

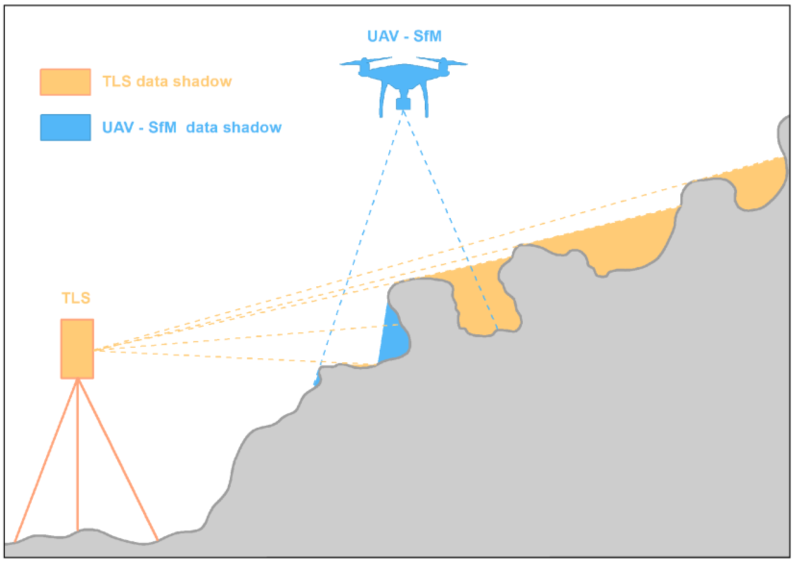

Fig. 1. Example of integrated TLS and UAV data acquisition for high-resolution surface modeling (adapted from Remote Sensing, 2019, CC BY 4.0).

In practice, this results in more accurate cadastral plans, reliable engineering measurements, and more realistic three-dimensional models.

The development of automated algorithms for point cloud alignment with GNSS coordinates further enhances the reliability of results and minimizes the need for manual intervention.

Table 1 Typical accuracies of different geodetic technologies

Technology	Horizontal Accuracy	Vertical Accuracy
GNSS (RTK/PPP)	8–15 mm (up to 2 cm in optimal conditions)	20–30 mm
TLS (Terrestrial Laser Scanning)	2–4 mm (up to 10 mm after georeferencing)	5–8 mm
GNSS + TLS (Integrated Solutions)	≤ 1 cm	≤ 2 cm
UAV–LiDAR	3–5 cm	5–8 cm

5. Applications of Integrated GNSS–TLS Technologies

Integrated GNSS–TLS systems are increasingly applied across various fields of geodesy and engineering. Key applications include:

- Cadastral and urban mapping, where high accuracy and spatial detail are required;
- 3D modeling of infrastructure and architectural objects, supporting BIM (Building Information Modeling) and Smart City projects [5];

- Monitoring of deformations and geodynamic processes, which requires a combination of global positioning and high local resolution;
- Archaeology and cultural heritage, enabling digital archiving and detailed analysis of valuable historical objects;
- Environmental monitoring, where three-dimensional models of terrain and vegetation are created to assess natural processes.

Thanks to these capabilities, integrated GNSS–TLS systems have become a standard tool for producing up-to-date, high-precision large-scale maps.

6. Conclusion

The integration of GNSS and TLS represents a natural progression in the development of modern geodesy. By combining the global accuracy of satellite systems with the high-resolution detail of laser scanning, this approach provides a new level of quality in spatial data.

This combination not only enhances measurement accuracy but also transforms the philosophy of surveying—from isolated procedures to integrated, automated workflows. Future developments are expected through further integration with unmanned systems, inertial sensors, and artificial intelligence algorithms [6].

Integrated GNSS–TLS solutions serve as a critical tool for producing high-quality large-scale maps, which form the foundation for sustainable territorial and infrastructure management

Acknowledgments

This scientific article under project number RD-08-117/06.02.2025 „Application of a specialized geographic information system for solving problems in the field of cadastre“ is funded.

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