

TOPOGRAPHY AND THE IMPORTANCE OF LIDAR MEASUREMENT SYSTEM FOR CIVIL ENGINEERING AND AVIATION

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ABSTRACT: Topography and LiDAR (Light Detection and Ranging) play a pivotal role in civil engineering, terrain analysis, and various scientific disciplines. Topography, the study and mapping of the Earth's natural and artificial surface provide critical information on elevation, slope, and landform characteristics, which is essential for infrastructure planning, environmental management, and risk mitigation. LiDAR enhances traditional surveying by generating high-resolution 3D models of the terrain through laser-based distance measurements. This technology allows for accurate mapping of complex landscapes, even beneath vegetation, and integrates with Geographic Information Systems (GIS) for advanced spatial analysis. Civil engineers utilize topographic and LiDAR data for site selection, infrastructure design, earthwork calculations, drainage and flood control, structural stability assessments, and urban planning. In aviation, topographic data aids pilots in navigation, terrain awareness, and safe flight operations. Despite challenges such as cost, weather sensitivity, and large data volumes, LiDAR continues to revolutionize the collection, visualization, and application of topographic information.

KEY WORDS: Topography, LiDAR, uses of LiDAR in civil engineering, uses of LiDAR in aviation

1. INTRODUCTION

Topography is the study and detailed mapping of the Earth's natural and artificial surface features. It focuses on the shape, elevation, and layout of landscapes. By analyzing these features, scientists and geographers can better understand how the Earth's surface has evolved over time and how it continues to change due to natural processes and human activity.

The practice of mapping topography dates back thousands of years, when people used basic tools to record the shapes of landforms. Today, with the advancement of technology, topographic mapping has become far more accurate and sophisticated. Modern methods use satellite imagery, aerial photography, Global Positioning

Systems (GPS), and Light Detection and Ranging (LiDAR) to capture precise measurements of elevation and terrain. These tools have allowed researchers to produce detailed topographic maps and digital elevation models (DEMs), which are essential for studying landscapes on local, regional, and global scales.

2. TOPOGRAPHY HISTORY

The history of topography begins in ancient times, with the first land measurements carried out to determine the size of plots of land. In our country, topography developed significantly in the 18th century with the first determinations of longitude and latitude for cities such as Bucharest and Târgoviște. In the 19th century, topography

was introduced as a subject of study in Romanian education through the contributions of figures like Gheorghe Asachi and Gheorghe Lazăr. Progress continued into the 20th century, and after the Second World War, further advancements were made.

Topography is essential for activities such as cadastral, urban planning, and construction.

It is carried out by authorized surveyors who measure land, draw up maps, and prepare the necessary documentation for various purposes, cadaster and property registration, urban planning, for developing general and detailed urban plans that guide the spatial development of cities and towns, construction and infrastructure.

3. UNDERSTANDING TOPOGRAPHY

Understanding topography is crucial for many fields. In civil engineering and urban planning, topographic maps guide the design of infrastructure such as roads, bridges, and buildings by revealing how land elevation and slope can affect construction. In environmental science, topography helps predict water flow, soil erosion, and the impact of natural disasters like landslides or floods. It also plays an important role in aviation and agriculture.

By mapping the shape of our planet, humans gain more than just a visual representation of the terrain; they gain a deeper understanding of the interconnected processes that shape our world. Topography connects geology, geography, and ecology, reminding us that the surface of the Earth is constantly changing. Whether used for scientific research, environmental protection, or exploration, the study of topography continues to be an essential tool for understanding the complexity and the beauty of our planet.

4. LiDAR SYSTEM

LiDAR (Light Detection and Ranging) is a remote sensing technology that uses laser pulses to measure distances to the Earth's surface or other objects. By emitting rapid laser light signals, often hundreds of thousands per second, and by measuring how long it takes for each pulse to return, LiDAR precisely calculates the distance between the sensor and the target. The result is a high-resolution 3D representation of the surface which can capture even minute variations in elevation and structure.

LiDAR operates on the same principle as radar or sonar, but instead of radio or sound waves, it uses light waves (typically in the near-infrared or green spectrum).

The LiDAR system consists of four main components: laser emitter that sends out short pulses of light toward the target, scanner and optics that direct the laser pulses across the area being surveyed, GPS (Global Positioning System) that records the precise location of the sensor, measurement unit (IMU, International Measurement Unit) that measures the orientation and movement of the LiDAR system to ensure positional accuracy. When each laser pulse hits an object (ground, tree, building, or water surface), part of the light is reflected back to the sensor. The time of flight (ToF) of each pulse is used to compute the distance: $\text{Distance of the object} = \text{light speed} \times \text{Time} / 2$

This process is also known as "Time of Flight" (ToF) measurement (Figure 1). Modern LiDAR systems are powerful enough to send up to 900,000 pulses per second.

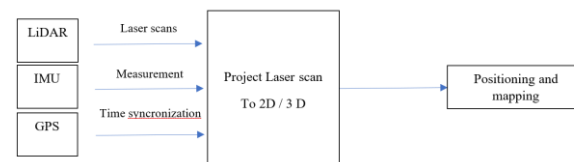


Figure 1. Functional block diagram of a LiDAR system (source: graphic diagram made by the authors)

LiDAR systems are classified based on their platform and purpose. Examples of the types of Lidar Systems:

- LiDAR mounted on airplanes, drones, or helicopters. Used for large-scale mapping and terrain modeling;
- bathymetric LiDAR that uses green light to penetrate water for underwater mapping;
- terrestrial LiDAR mounted on tripods or vehicles, used for detailed site scans, building modeling, and infrastructure analysis;
- mobile LiDAR mounted on moving vehicles used for mapping roads, cities, and transportation networks.

Lidar System provides many advantages, such as: providing centimeter-level precision, far exceeding traditional survey methods, collecting data very fast over vast or inaccessible areas, measuring the ground surface beneath trees and vegetation using multiple return pulses, producing detailed digital elevation models and digital surface models, integrating with Geographic Information Systems for spatial analysis. [1]

5. DISCIPLINES THAT INTEGRATE LIDAR

LiDAR has become indispensable in numerous scientific and engineering domains such as: civil engineering and construction (terrain analysis and measurement, 3D city modeling, monitoring structural deformations, etc.), environmental and geographical studies (mapping terrain, forest evaluations, erosion detection, etc.), archaeology (revealing ancient structures beneath dense vegetation), urban planning (creating accurate 3D maps for infrastructure and smart city projects), autonomous vehicles (used in real-time for obstacle detection and navigation systems in self-driving cars).



Figure 2. Self-driving taxi using LiDAR system (source: photo taken by the authors)

Despite its many advantages, LiDAR also has challenges. Equipment and data processing are expensive compared to traditional surveying tools, cloud cover, rain, or fog can interfere with laser accuracy, the massive datasets are requiring specialized software and expertise to process, highly reflective or absorbent surfaces (e.g., water, glass) may cause signal loss or distortion. New developments can include miniaturization (minimizing the sensors and other electronic components), using faster computers that can enable rapid live 3D modeling and analysis, integration with AI that can recognize terrain and can automated change detection and other improvements that increase speed and accuracy of functioning. [2]

6. HOW TOPOGRAPHY IS USED BY CIVIL ENGINEERS

Topography plays a vital role in civil engineering because it provides essential information about the shape, elevation, and features of the land. Understanding the topography of an area allows engineers to design, plan, and build structures safely, efficiently, and sustainably.

Before any construction begins, civil engineers analyze topographic maps to determine the most suitable location for a project. The slope, elevation, and drainage patterns of the land influence where buildings, roads, bridges, or dams can be safely and economically built. For example,

areas with steep slopes might require more excavation or retaining walls, while flat areas may be better suited for large structures.

Topographic surveys are essential for creating accurate design plans for roads, railways, pipelines, and drainage systems. Engineers use elevation data to design routes that minimize steep grades and reduce construction costs. For instance, when designing a road through hilly terrain, topographic data helps engineers determine where to cut through hills or fill valleys to achieve a smooth and safe path.

Civil engineers use topographic maps to design effective drainage systems, stormwater management structures, and flood control projects. Understanding the natural flow of water helps prevent problems like soil erosion, flooding, and waterlogging around buildings and infrastructure.

Accurate topographic data ensures that earthwork operations are cost-effective and that the final surface matches the design plans.

Topography influences the stability of structures such as bridges, dams, and buildings. Engineers study the terrain to identify potential issues like landslides, unstable slopes, or areas prone to erosion. This information helps them design foundations and retaining structures that can withstand natural forces and ensure long-term safety.

Today, civil engineers use advanced tools like LiDAR drones, and GIS (Geographic Information Systems) to create highly accurate digital elevation models. These technologies allow for better visualization, simulation, and decision-making throughout the design and construction process.

The integration of LiDAR with topography illustrates the synergy between advanced technology and traditional geographic understanding. For civil engineers, it

translates to precise planning, risk mitigation, and environmentally sensitive design. For pilots, it provides a reliable and detailed view of the terrain, enhancing situational awareness and safety. Across disciplines, LiDAR bridges the gap between observation and analysis, allowing humans to understand, model, and interact with the Earth's complex surface in ways that were previously impossible. [3,4]

7. HOW TOPOGRAPHY IS USED BY PILOTS

Topography plays a crucial role in aviation because it helps pilots understand the shape and elevation of the land below them. Knowing the terrain is essential for safe flight planning, navigation, and avoiding obstacles. Pilots rely on topographic information.

Pilots use topographic maps and terrain data displayed on the plane systems to identify high ground, ridges, or obstacles along their flight path. Modern aircraft are equipped with Terrain Awareness and Warning Systems or Ground Proximity Warning Systems that use digital elevation models derived from topographic data to alert pilots if they are flying too close to terrain.

Before takeoff, pilots study topographical charts to plan routes that avoid mountainous areas or other dangerous terrain features, especially in poor weather or at night when visibility is limited. These charts show contour lines, elevation points, and terrain shading, allowing pilots to determine safe altitudes. For example, when flying over mountain ranges, pilots must maintain a minimum safe altitude based on topographic elevations.

Topography also affects how aircraft approach and land at airports. Many airports are located near hills, valleys, or plateaus, which can influence wind patterns and approach paths. Pilots use topographic data and aeronautical charts to understand the surrounding terrain and plan their descent

safely. Some airports have terrain-specific approach procedures that guide pilots around nearby obstacles.

Terrain has a direct impact on local weather conditions and wind behavior. Mountains can create turbulence, downdrafts, or updrafts that affect an aircraft's stability. Understanding the topography of an area helps pilots anticipate these conditions and adjust their flight path accordingly. For example, flying near mountain ranges often requires extra caution due to strong crosswinds or wind shear.

During the flight, pilots use the shape of the land, rivers, lakes, and mountains as visual landmarks to confirm their position. Accurate topographic maps help them identify these features and stay oriented during flight. [5]

8. CONCLUSION

Topography and LiDAR technology are intrinsically linked in their applications across civil engineering, terrain analysis, and aviation, providing a comprehensive understanding of the Earth's surface that informs both planning and operational safety. Topography, the study of the shape, elevation, and features of landforms, forms the foundation of these applications. By examining mountains, valleys, rivers, plains, and human-made structures, engineers and scientists can analyze how the terrain influences construction, water flow, erosion, and urban development. Traditionally, topographic surveys relied on manual measurements and visual observations, but modern technological advancements, particularly LiDAR systems, have revolutionized the precision and efficiency of terrain mapping. It bridges the gap between traditional surveying and modern digital mapping by providing high-precision, 3D insights into both natural and built environments. As technology advances, LiDAR's integration with drones,

artificial intelligence, and real-time analytics will continue to transform engineering, environmental management, and spatial sciences, making it one of the most powerful tools for understanding and shaping the surface of our planet.

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