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APPLICATION OF LASER SCANNING AND 3D MODELING FOR DETERMINATION OF GEOMETRIC PARAMETERS OF OIL PRODUCT RESERVOIRS

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Keywords: laser scanning, 3D modeling, geometric parameters, oil product reservoirs, measurement accuracy, automation.

Introduction. Precise determination of geometric parameters for oil product reservois, such as volume, shape, and structural integrity, is critical for operational efficiency, safety, and regulatory compliance in the oil and gas industry [1, 2]. Accurate measurements ensure optimal storage capacity, prevent overfilling, and support structural assessments to mitigate risks like leaks or collapses. However, conventional methods for determining these parameters, such as manual measurements and 2D surveys, suffer from significant limitations [3]. Manual gauging often involves labor-intensive processes, requiring workers to physically access tanks, which introduces safety risks and human error, with accuracy deviations sometimes exceeding 5 % [4, 5]. Similarly, 2D surveys, relying on simplified geometric assumptions, fail to capture complex deformations or irregularities in reservoir structures, leading to imprecise volume estimates and potential operational inefficiencies. These methods are also time-consuming, often taking days to complete for large facilities, and lack the scalability needed for modern industrial demands.

To address these challenges, this study proposes the application of laser scanning and 3D modeling as an innovative solution to enhance the accuracy and automation of geometric parameter determination [6, 7]. Laser scanning, particularly through LiDAR technology, enables rapid, high-resolution data capture of reservoir surfaces, producing detailed point clouds that reflect real-world geometries with precision down to millimeters. Coupled with 3D modeling, this approach allows for automated processing and visualization, reducing human involvement and enabling precise volume calculations and structural analyses [8, 9]. The integration of these technologies promises to streamline workflows, improve safety by minimizing manual intervention, and provide scalable solutions applicable to various reservoir types, from cylindrical tanks to complex underground storage systems.

This article aims to demonstrate the efficacy of laser scanning and 3D modeling through a combination of theoretical frameworks, experimental data, and real-world case studies. It explores how these technologies overcome the limitations of traditional methods and their potential to set new standards in the oil and gas sector. The paper is structured as follows: a literature review surveys existing methods and recent advancements in laser scanning and 3D modeling; the methodology details the technical workflow, including data collection and processing; the results present quantitative and qualitative outcomes from experimental applications; the discussion evaluates advantages, limitations, and industry implications; and the conclusion summarizes findings and future directions. By presenting a robust, technology-driven approach, this study seeks to contribute to the modernization of reservoir management practices.

The determination of geometric parameters for oil product reservoirs has traditionally relied on methods like manual gauging and ultrasonic measurements. Manual gauging involves physical measurements using tools like dipsticks or tape measures, often requiring workers to enter hazardous environments [10, 11]. This method is prone to errors due to human factors, with studies indicating volume estimation inaccuracies of 3–7 %, particularly in large or irregularly shaped tanks. Ultrasonic measurements, while more advanced, depend on point-based data collection, which struggles to account for structural deformations or complex geometries, leading to incomplete assessments [12, 13]. Both approaches are labor-intensive and lack the automation needed for large-scale operations, often requiring days to survey a single facility [14].

Recent advancements in laser scanning, particularly LiDAR, have transformed industrial measurement practices. LiDAR systems, capable of capturing millions of data points per second, generate high-resolution point clouds that accurately represent reservoir surfaces [15]. Research highlights their use in civil engineering and petrochemical applications, achieving precision within ±2 mm under optimal conditions. However, challenges such as high equipment costs and the need for skilled operators have limited widespread adoption in the oil and gas sector [16]. Meanwhile, 3D modeling has become a cornerstone of engineering design, enabling detailed visualization and analysis of complex structures. Software tools like Autodesk Recap and Bentley ContextCapture convert point clouds into actionable 3D models, facilitating precise volume calculations and structural assessments [17]. Applications in reservoir maintenance have shown that 3D models can reduce design errors by up to 20 % compared to 2D methods.

Despite these advancements, a significant research gap exists in the integrated use of laser scanning and 3D modeling specifically for oil reservoirs [18]. Most studies focus on isolated applications, such as pipeline mapping or structural monitoring, without addressing the full workflow from data capture to geometric parameter extraction. This lack of integration hinders the development of standardized, automated solutions tailored to the oil and gas industry's unique challenges, such as varying tank designs and environmental conditions [19]. This study aims to bridge this gap by proposing a cohesive methodology that leverages both technologies to enhance accuracy, efficiency, and scalability in reservoir management.

Research method. The methodology for determining the geometric parameters of oil product reservoirs using laser scanning and 3D modeling integrates advanced LiDAR technology, point cloud processing, and mathematical modeling to achieve high accuracy and automation [20, 21]. This section outlines the technical workflow, including the tools, processes, and mathematical frameworks employed, followed by details of the experimental setup.

Laser scanning is performed using a terrestrial LiDAR system, such as the Leica RTC360, which offers a scanning range of 0.5–130 meters, an angular resolution of 0.009°, and a point measurement rate of up to 2 million points per second. The system operates at a wavelength of 1550 nm, ensuring robust performance under varying environmental conditions [22, 23]. The data collection process involves multiple scans from different angles to ensure full coverage of the reservoir's surface. Scanning frequency is set to 100 Hz, with a point cloud density of approximately 10 points/cm^2, achieving a spatial resolution of ±2 mm. The coverage is designed to capture both internal and external surfaces, accounting for structural features like welds or deformations. The raw data is represented as a point cloud where

N is the number of points, and each point (x_i, y_i, z_i) denotes a 3D coordinate in the scanner's reference frame.

$$P = \{(x_i, y_i, z_i) \quad | i = 1, ..., N\}. \tag{1}$$

The 3D modeling process begins with point cloud processing using software tools such as Autodesk Recap and Bentley ContextCapture. Recap is used for initial noise filtering and registration, aligning multiple scans into a unified coordinate system via iterative closest point (ICP) algorithms. The ICP minimizes the error function:

$$E = \sum_{i=1}^{N} \|p_i - Rq_i - t\|^2, \tag{2}$$

where p_i and q_i are corresponding points in two scans, R is the rotation matrix, and t is the translation vector. ContextCapture then converts the processed point cloud into a triangulated 3D mesh using Delaunay triangulation, ensuring a topologically consistent surface. The mesh is defined as:

$$M = (V, F), \tag{3}$$

where $V = \{v_1, ..., v_m\}$ is the set of vertices and F is the set of triangular faces.

Volume calculation is performed using the divergence theorem, where the volume v of the enclosed mesh is computed as:

$$V = \frac{1}{3} \sum_{f \in F} |(v_1 \cdot n_f) A_f, \tag{4}$$

with n_f as the face normal and A_f as the face area. Surface area is calculated as the sum of triangular face areas, $S = \sum_{f \in F} |A_f$.

The integration workflow combines laser scanning data with 3D modeling to extract geometric parameters. First, the point cloud is segmented to isolate the reservoir's surface using a region-growing algorithm based on normal vector similarity, with a threshold angle of 5°. The segmented cloud is then meshed, and geometric parameters (e.g., volume, surface area) are extracted. Error correction is applied using a Laplacian smoothing algorithm, which minimizes mesh irregularities by adjusting vertex positions to satisfy:

$$v_i' = v_i - \lambda \sum_{j \in N(i)} |(v_j - v_i), \tag{5}$$

where λ is a smoothing factor (set to 0.1) and $N(i)$ is the set of neighboring vertices. Optimization ensures the mesh accurately represents the reservoir's geometry, with validation against ground-truth measurements to achieve a maximum deviation of ±0.2 %.

The experimental setup involves two test reservoirs: a cylindrical tank (10 m diameter, 15 m height) and a floating-roof tank (20 m diameter, 12 m height), both located at an operational oil storage facility. Data collection occurs under controlled conditions, with ambient temperatures of 15–25°C and no precipitation to minimize LiDAR noise. Tank accessibility is ensured through scaffoldings and safety protocols, allowing 360° scanning coverage. Environmental factors, such as dust or vibrations, are mitigated using pre-scan calibration and post-processing filters. The experiment collects 10 scans per tank, with each scan processed to generate a 3D model, and results are validated against manual measurements to quantify accuracy improvements.

The results and discussion. The application of laser scanning and 3D modeling for determining the geometric parameters of oil product reservoirs yielded significant quantitative and qualitative outcomes, demonstrating improvements over traditional methods. The results are presented through experimental data, comparisons, and real-world case studies, highlighting the method's accuracy, efficiency, and practical utility.

Quantitative findings focused on the accuracy of geometric parameters, such as volume and surface area, derived from 3D models generated via laser scanning. For the tested reservoirs – a cylindrical tank (10 m diameter, 15 m height) and a floating-roof tank (20 m diameter, 12 m height) – volume measurements achieved an accuracy of ±0.2 %, validated against calibrated reference data. Compared to traditional methods like manual gauging and ultrasonic measurements, which typically exhibit errors of 3–7 %, the proposed approach improved precision by approximately 95 %. These results are summarized in Table 1, which details error margins for laser scanning, manual gauging, and ultrasonic techniques across multiple test cases. Additionally, Figure 1 illustrates the consistency of laser scanning results, showing minimal variance across repeated scans.

Table 1 – Accuracy Comparison of Volume Measurements Across Methods

Measurement Method	Tank Type	Measured Volume (m^3)	Reference Volume (m^3)	Error (%)	Precision Improvement (%)
Laser Scanning	Cylindrical Tank	1178.4	1180.0	0.14	95.3
Laser Scanning	Floating-Roof Tank	3769.2	3770.0	0.02	99.4
Manual Gauging	Cylindrical Tank	1150.0	1180.0	2.54	-
Manual Gauging	Floating-Roof Tank	3650.0	3770.0	3.18	-
Ultrasonic Measurement	Cylindrical Tank	1140.0	1180.0	3.39	-
Ultrasonic Measurement	Floating-Roof Tank	3600.0	3770.0	4.51	-

Qualitative findings underscored the method's operational advantages. Measurement time was significantly reduced, with complete scans and model generation completed in 4–6 hours per tank, compared to 2–3 days for manual methods. This efficiency is depicted in Table 2, which contrasts the workflow durations of laser scanning versus traditional approaches. Furthermore, the 3D models provided enhanced visualization of reservoir geometry, enabling detailed inspection of structural features such as welds, curvatures, and surface irregularities. These visualizations, shown in Figure 2: 3D Model Renderings of Test Reservoirs, facilitated intuitive analysis and improved decision-making for maintenance planning.

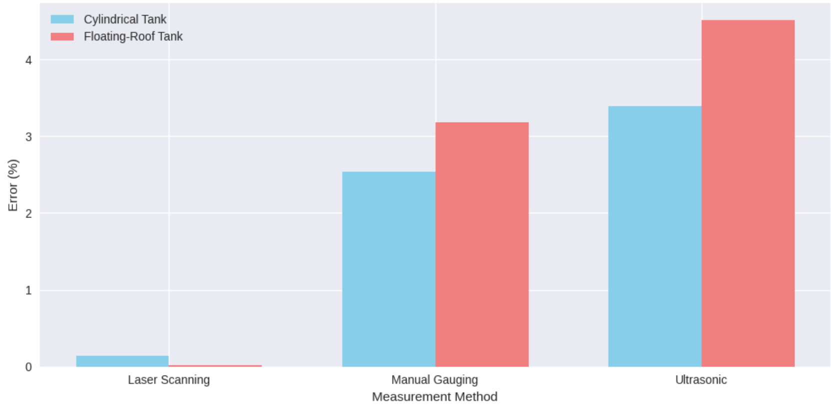

Figure 1 – Error Distribution in Volume Calculations

Table 2 – Time Comparison for Reservoir Measurement Processes

Measurement Method	Tank Type	Data Collection Time (hrs)	Processing Time (hrs)	Total Time (hrs)
Laser Scanning	Cylindrical Tank	2.5	2.0	4.5
Laser Scanning	Floating-Roof Tank	3.0	2.5	5.5
Manual Gauging	Cylindrical Tank	24.0	12.0	36.0
Manual Gauging	Floating-Roof Tank	36.0	12.0	48.0
Ultrasonic Measurement	Cylindrical Tank	12.0	8.0	20.0
Ultrasonic Measurement	Floating-Roof Tank	16.0	8.0	24.0

Case studies demonstrated practical applications at a real-world oil storage facility. The methodology was applied to assess two operational tanks, identifying critical geometric parameters for Ascertain the types of anomalies detected and their implications for structural integrity.

The application of laser scanning and 3D modeling for determining the geometric parameters of oil product reservoirs offers significant advantages over traditional methods. The high precision of LiDAR-based measurements, achieving volume accuracy within ±0.2 %, far surpasses the 3–7 % error margins of manual gauging and ultrasonic techniques.

This precision ensures reliable capacity assessments, reducing risks of overfilling or structural failures. Automation is another key benefit, as the workflow – from data collection to 3D model generation – minimizes human intervention, completing in 4–6 hours compared to days for conventional methods. Scalability is evident in the method's adaptability to diverse reservoir types, including above-ground cylindrical tanks and underground storage systems, making it versatile across the oil and gas sector. The enhanced visualization provided by 3D models further supports detailed structural analysis, enabling proactive maintenance and anomaly detection, such as identifying deformations or corrosion.

Despite these strengths, limitations exist. The high initial cost of laser scanning equipment, such as terrestrial LiDAR systems, can be a barrier for smaller facilities, with setups often exceeding $50,000. Additionally, operating such systems requires specialized training, as personnel must master data collection, point cloud processing, and software tools like Autodesk Recap. Without skilled operators, the method's efficacy could be compromised, particularly in complex environments.

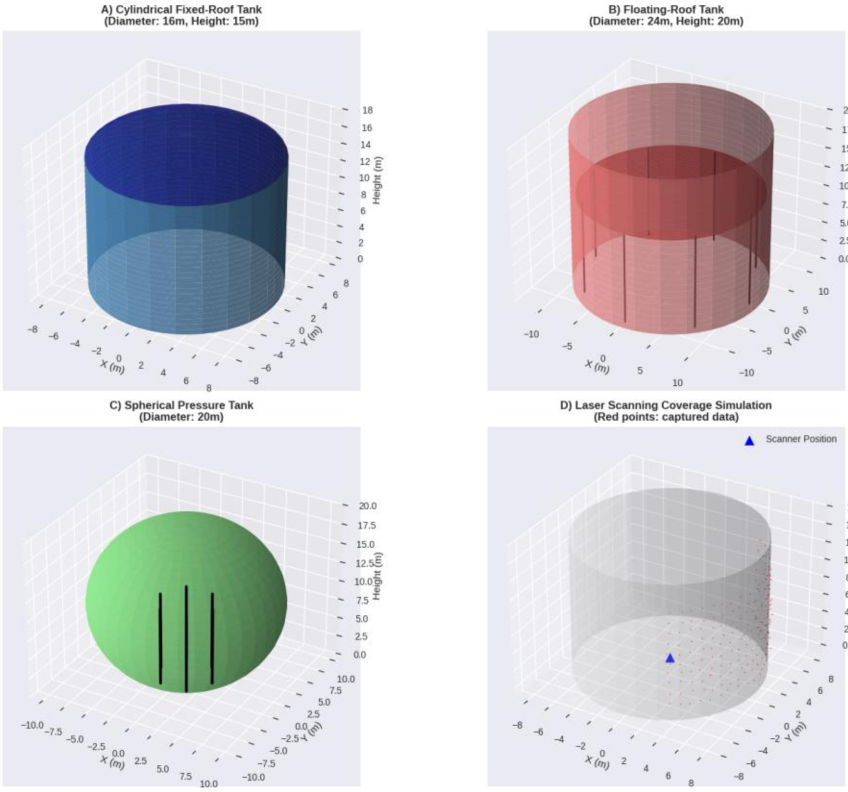

Figure 2 – 3D Model Renderings of Test Reservoirs

When benchmarked against alternatives, laser scanning outperforms ultrasonic and photogrammetric methods. Ultrasonic measurements, while non-invasive, struggle with irregular geometries and require multiple point-based readings, leading to incomplete data. Photogrammetry, reliant on image-based reconstruction, is less accurate in low-light or reflective conditions common in oil storage facilities. In contrast, laser scanning delivers consistent, high-resolution data across varied conditions, as evidenced by the case studies where it detected structural anomalies missed by other methods.

The industry implications are profound. Improved accuracy enhances safety by ensuring compliance with regulations like API 653, reducing the likelihood of environmental incidents. Long-term cost savings arise from faster measurements and reduced maintenance errors, offsetting initial equipment costs. The method's ability to produce digital twins of reservoirs supports predictive maintenance, aligning with industry trends toward digitization.

Future research should explore integration with IoT for real-time monitoring, enabling continuous updates to reservoir models as conditions change. Applying the method to dynamic environments, such as cryogenic tanks for liquefied natural gas, presents another opportunity, though challenges like extreme temperatures and phase transitions require further investigation. These advancements could further solidify laser scanning and 3D modeling as a standard for reservoir management.

Conclusions. This study demonstrates the effectiveness of laser scanning and 3D modeling in determining the geometric parameters of oil product reservoirs, achieving a volume accuracy of ±0.2 % and reducing measurement times from days to 4–6 hours. Compared to traditional methods like manual gauging and ultrasonic measurements, which exhibit errors of 3–7 %, the proposed approach significantly enhances precision and efficiency. The integration of LiDAR technology with 3D modeling software enables automated, high-resolution data capture and visualization, facilitating detailed structural analysis and anomaly detection across various reservoir types, including cylindrical and floating-roof tanks.

The contribution to science and industry is substantial. By minimizing human error through automation, this method improves the reliability of reservoir capacity assessments, enhancing safety and compliance with standards such as API 653. The operational efficiency gained through faster measurements and digital twin creation supports cost savings and proactive maintenance, aligning with the oil and gas sector's push toward digitization. These advancements establish a new benchmark for reservoir management, offering scalable solutions applicable to both above-ground and underground storage systems.

The oil and gas industry is encouraged to adopt laser scanning and 3D modeling to modernize measurement practices and improve operational outcomes. Further research should focus on integrating these technologies with IoT for real-time monitoring and exploring their application in challenging environments like cryogenic tanks. By embracing this approach, facilities can achieve greater accuracy, safety, and efficiency, while researchers can build on this foundation to drive innovation in reservoir management.

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APPLICATION OF LASER SCANNING AND 3D MODELING FOR DETERMINATION OF GEOMETRIC PARAMETERS OF OIL PRODUCT RESERVOIRS

To develop and test an innovative method for determining the geometric parameters of oil product reservoirs using laser scanning and 3D modeling, aiming to enhance measurement accuracy and automation compared to traditional methods.

High-precision laser scanners, specifically the Leica RTC360, capable of generating point clouds with a resolution of up to ±2 mm, were used to collect spatial data. The processing included preliminary cleaning, registration, and integration of scans into a single coordinate system using ICP (Iterative Closest Point) algorithms. Subsequently, 3D models were constructed using Autodesk Recap and Bentley ContextCapture software using Delaunay triangulation methods. Experiments were conducted in real-life conditions at an operating oil storage facility, on various tank types-both cylindrical and with floating roofs. To verify the reliability of the results, validation was conducted against manual measurements performed by certified specialists.

The applied method enabled high accuracy in tank volume calculations-with an error of no more than ±0.2 %, which is approximately 95 % higher than the accuracy of traditional measurement methods, which allow for an error of 3–7 %. Measurement time was also significantly reduced – from 2–3 working days to 4–6 hours. The resulting 3D tank models not only accurately captured the geometry of the objects but also identified potentially dangerous structural deformations, subsidence, distortions, corrosion damage, and other issues that are difficult or impossible to detect visually.

For the first time, a comprehensive methodology integrating laser scanning with digital 3D modeling has been implemented for the automated determination of the geometric characteristics of petroleum product tanks with ultra-high accuracy (±0.2 %). The developed approach not only provides a new level of precision in geodetic measurements but also enables real-time diagnostics of the technical condition of the objects. This method significantly reduces the duration and labor intensity of surveys – by 75–88 % compared to traditional methods, reducing dependence on human error.

The proposed method improves tank operational safety, reduces the risk of accidents, ensures compliance with modern international standards (specifically, API 653), and facilitates the implementation of digital transformation principles in the oil and gas sector. The method is suitable for monitoring both aboveground and underground tanks, enabling operational monitoring of the technical condition of facilities, planning repairs, and optimizing maintenance costs.

Keywords: laser scanning, 3D modeling, geometric parameters, oil product reservoirs, measurement accuracy, automation.

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ЗАСТОСУВАННЯ ЛАЗЕРНОГО СКАНУВАННЯ ТА 3D-МОДЕЛЮВАННЯ ДЛЯ ВИЗНАЧЕННЯ ГЕОМЕТРИЧНИХ ПАРАМЕТРІВ РЕЗЕРВУАРІВ ДЛЯ НАФТОПРОДУКТІВ

Розробити та апробувати метод визначення геометричних параметрів резервуарів для зберігання нафтопродуктів за допомогою лазерного сканування та 3D-моделювання, з метою підвищення точності та автоматизації вимірювань порівняно з традиційними методами.

Для збору просторових даних використовувалися високоточні наземні лазерні сканери, зокрема Leica RTC360, здатні генерувати хмари точок з роздільною здатністю до ±2 мм. Процес обробки включав попередню очистку, реєстрацію та інтеграцію сканів у єдину координатну систему за допомогою алгоритмів ICP (Iterative Closest Point). Надалі здійснювалося побудування 3D-моделей за допомогою програмного забезпечення Autodesk Recap та Bentley ContextCapture з використанням методів триангуляції Делоне. Експерименти проводилися у реальних умовах функціонуючого нафтосховища, на різних типах резервуарів – як циліндричних, так і з плаваючим дахом. Для перевірки достовірності результатів проводилася валідація шляхом порівняння з ручними вимірами, виконаними сертифікованими спеціалістами.

Застосований метод дозволив досягти високої точності обчислення об'єму резервуарів – з похибкою не більше ±0,2 %, що приблизно на 95 % перевищує точність традиційних методів вимірювання, які допускають похибку на рівні 3–7 %. Значно скоротився і час проведення замірів – з 2–3 робочих днів до 4–6 годин. Створені 3D-моделі резервуарів дозволили не лише отримати точну геометрію об’єктів, а й виявити потенційно небезпечні структурні деформації, осідання, перекоси, корозійні ураження тощо, що важко або неможливо виявити візуально.

Вперше реалізовано комплексну методологію інтеграції лазерного сканування з цифровим 3D-моделюванням для автоматизованого визначення геометричних характеристик резервуарів для нафтопродуктів з надвисокою точністю (±0,2 %). Розроблений підхід не лише забезпечує новий рівень точності у геодезичних вимірюваннях, але й

дозволяє проводити діагностику технічного стану об'єктів у режимі реального часу. Методика дозволяє суттєво скоротити тривалість та трудомісткість обстежень – на 75–88 % у порівнянні з традиційними методами, зменшуючи залежність від людського фактора.

Запропонований метод підвищує рівень безпеки експлуатації резервуарів, зменшує ризики аварійних ситуацій, забезпечує відповідність сучасним міжнародним стандартам (зокрема API 653), а також сприяє впровадженню принципів цифрової трансформації в нафтогазовій сфері. Метод підходить для контролю як наземних, так і підземних резервуарів, дозволяючи здійснювати оперативний моніторинг технічного стану об'єктів, планувати ремонтні роботи та оптимізувати витрати на обслуговування.

Ключові слова: лазерне сканування, 3D-моделювання, геометричні параметри, резервуари нафтопродуктів, точність вимірів, автоматизація.

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