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Performance Comparison of Various Software Tools in Photogrammetry-Based Digitization and Visualization of Energy Infrastructure Objects

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Abstract

This study presents a comparative analysis of software efficiency for photogrammetric digitization and visualization of energy infrastructure objects. Experimental evaluation was conducted on a production boiler house section using Agisoft Metashape, 3DF Zephyr, Meshroom, RealityCapture, Pix4D, and the neural platform LumaAI. Results demonstrate that RealityCapture delivers superior reconstruction accuracy (1-10 mm error) and geometric detail preservation under complex reflective surface conditions, attributable to its hybrid data processing algorithms and GPU optimization. LumaAI exhibits rapid data processing capabilities and hidden area reconstruction technology (NeRF), but remains unsuitable for digitizing classified infrastructure due to data leakage risks.

Critical limitations were identified for Meshroom (inefficiency with large frame sets) and Pix4D (inadaptability to terrestrial photogrammetry). Sanction-related deployment challenges for RealityCapture in the Russian Federation are highlighted. The findings substantiate the necessity for specialized domestic solutions integrating classical method precision with AI algorithms while ensuring cybersecurity. This research establishes fundamental software selection criteria for energy asset digitization, digital twin development, and VR simulator creation.

Keywords: photogrammetry, point cloud, visualization, digital model, accuracy, software.

Introduction

A pressing challenge in modern energy is the visualization and creation of accurate digital models of energy facilities [1-4], including their key components – boilers, turbines, transformers, and generators, pipelines and valves – for generating up-to-date plans and schematics, training personnel through detailed visualization, and monitoring technical condition, planning repairs, and managing assets. Traditional surveying and documentation methods are often highly labor-intensive, entail significant risks to personnel (especially when measurements are required at height, in hard-to-reach areas, or, as is frequently the case, on operational equipment), and fail to provide the necessary level of detail, accuracy, and data completeness [5-8].

While laser 3D scanning can offer high accuracy and data acquisition speed, it also has several drawbacks that sometimes preclude its use [9-10]. Key limitations include: the very high cost of equipment; the inability to scan in hard-to-reach areas (e.g., behind steam boilers where piping obstructs tripod placement); the difficulty of scanning in the presence of numerous reflective surfaces (e.g., metallic insulation on pipelines and boilers), which causes signal multi-path reflection leading to ghosting or incorrect object representation; and the necessity to disable fire suppression systems with infrared sensors (as the laser beam triggers false alarms). In this context, photogrammetry emerges as an effective and, importantly, accessible tool for the contactless digitization of industrial and energy facilities.

The application of photogrammetry for creating highly detailed visualizations [11-14] and point clouds when working with energy assets is driven by several significant advantages. It enables the sufficiently accurate and high-resolution reconstruction of complex equipment and structure geometry in their actual operational state, including hard-to-access zones, without interfering with the technological process or halting production [15]. The resulting point clouds or, if required, polygonal 3D models, can serve as the foundation for creating digital twins, performing precision measurements, identifying defects (corrosion, deformations, insulator damage), and enabling realistic visualization of objects in interactive environments or augmented reality systems for personnel training and emergency scenario simulation [16-18].

The effectiveness of the photogrammetry process – from image capture to the generation of final digital products (point clouds and 3D models) – depends significantly on the software (SW) used. Different software employs diverse algorithms for image stitching, point cloud generation, noise filtering, and texturing, which directly impacts accuracy, detail, processing speed, and, ultimately, the suitability of the results for solving specific tasks. Therefore, a systematic comparison of the effectiveness of different software in the context of digitizing and visualizing energy assets via photogrammetry represents an urgent scientific and practical problem. Addressing this problem aims to optimize tool selection to ensure maximum quality and reliability of digital representations.

The aim of this work is a comparative analysis of the effectiveness of various software packages in creating point clouds of energy assets through photogrammetry.

Methodology

The experiment was conducted using the most common desktop photogrammetry software: Agisoft Metashape version 2.2.1, 3DF Zephyr version 8.017, Meshroom version 2023.3.0, RealityCapture version 2.0.1, and Pix4D version 1.76.1, along with the AI-based Luma.ai service. Each software package was processed independently in several stages. Desktop software was configured according to recommendations in the official documentation.

The source video footage was automatically converted into 3600 individual frames for input into the desktop software. This footage was captured under static lighting conditions at 5K resolution, 60 frames per second (FPS), using a linear lens on a GoPro 10 Black camera. Video clips for Luma.ai were uploaded in their original format.

The PC specifications for processing with desktop software were: Intel Core i7-13650HX processor, NVIDIA GeForce RTX 4060 GPU, and 32 GB DDR5 RAM. These specifications are irrelevant for Luma.ai, as file processing occurs on remote servers. Processing time was recorded for the desktop software to correlate resource expenditure with output quality.

The digitization target was a section of an industrial boiler room, comprising a boiler with pipelines, shut-off valves, a pump group, and an automation control cabinet. All elements feature diverse and complex geometries, are made from various materials (including highly reflective surfaces), and are compactly arranged, making measurements challenging with classical methods.

The accuracy assessment of the point clouds generated during the experiment was performed in NanoCAD x64 version 24.0. The appearance of the surveyed section is shown in Fig. 1.

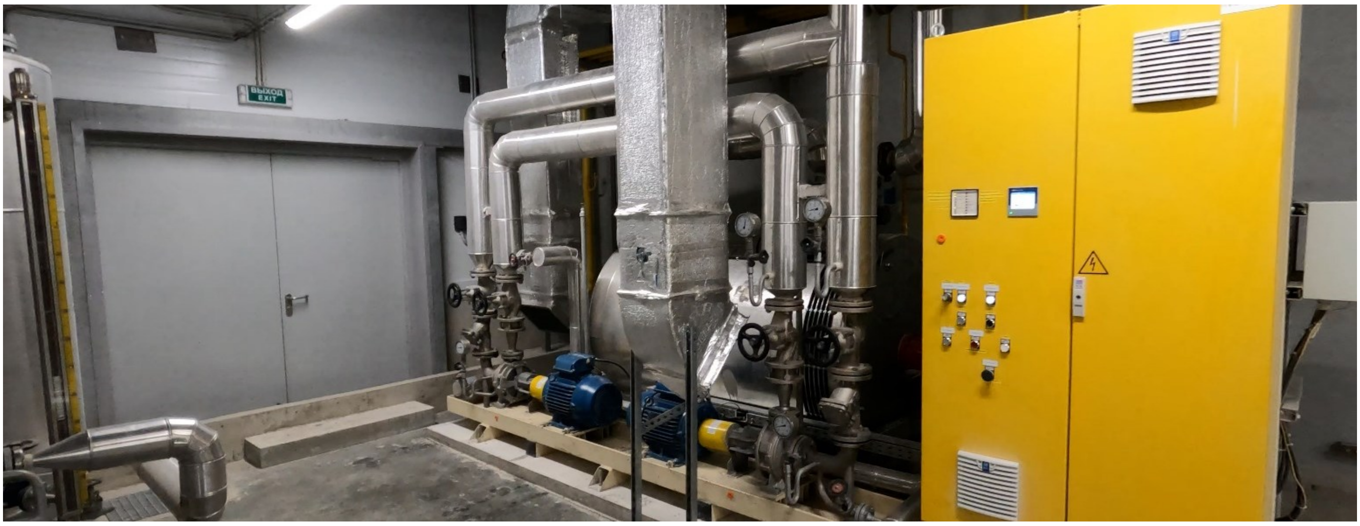


Fig. 1. Appearance of the boiler room section

Results

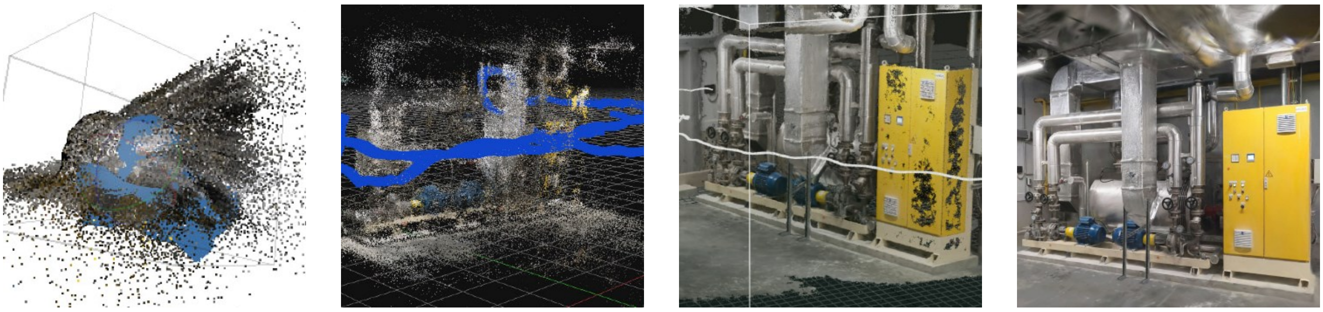
Meshroom and Pix4D: Both terminated processing due to critical errors and failed to generate a complete point cloud. For Meshroom, the high number of frames and the object's complexity proved critical. More stable operation in Meshroom would require reducing the number of images and performing manual classification and frame positioning calibration. A notable advantage of Meshroom is its open node-based programming system, allowing for workflow customization and potential improvements. Pix4D also failed to process the source material, despite being drone photogrammetry software designed to handle significantly larger frame counts, including direct video processing capabilities.

Agisoft Metashape: Processing took 1 hour and 30 minutes. The resulting output (Fig. 2a) cannot be considered fully satisfactory. The point cloud contains excessive noise, numerous inaccuracies, and deviations, rendering it unsuitable for either visualization or engineering purposes.

3DF Zephyr: Processing took 4 hours and yielded better results than Agisoft Metashape. The generated point cloud (Fig. 2b) has a clear, identifiable structure. The camera distance and trajectory were correctly determined, and the main features of large objects (pumps, boiler, control cabinet) are discernible. However, the cloud is sparse and noisy. Small objects (shut-off valves, instrumentation) and pipelines are indistinguishable.

RealityCapture (RC): Successfully completed the task in 3 hours. The resulting point cloud (Fig. 2c) is sharp, with correctly determined camera distance and trajectory. The geometry and textures of all elements are accurately represented. Deviation in key dimensions ranges from 1 to 10 mm, with the highest values observed on large, uniform planes (e.g., control cabinet doors, floor, walls). These deviations are attributed to a lack of unique image features (cracks, diverse textures, geometric shapes) needed for stable Structure from Motion (SfM) algorithm operation through point matching between frames. Nevertheless, the achieved accuracy and point density make the cloud suitable for engineering tasks, such as creating as-built documentation – particularly valuable for long-operational facilities where original documentation is missing or outdated. RC's broad support for export formats (FBX, OBJ, PLY, ABC, GLB, XYZ, LAS, STL, etc.) and direct integration into Unreal Engine enable wide application in energy engineering and visualization [19]. Additionally, RealityCapture incorporates notable technologies for superior results: hybrid processing (combining photos and LiDAR data for metric accuracy), core-level GPU acceleration with multi-GPU/multi-computer task distribution, automatic camera calibration, and georeferencing (GPS tags, GCPs). A key drawback at the time of writing is installation complexity. The software is officially unavailable in the Russian Federation, requiring creation of a foreign account, switching the OS region to Europe/USA, and using a VPN.

LumaAI: The final system evaluated was the neural network LumaAI. Processing the video resulted in a clear point cloud (Fig. 2d) without texture or geometric distortions. Deviation in key dimensions ranges from 1 to 15 mm, comparable to RealityCapture, though deviations on large planes can reach ±10–50 mm. Point clouds can be exported in major formats (PLY, XYZ, LAS). A significant advantage of LumaAI over all desktop software is its use of Neural Radiance Fields (NeRF) technology. This allows the AI to predict the color and density of points in 3D space based on video data, enabling geometry reconstruction even in areas occluded from the camera. Furthermore, unlike desktop software, using LumaAI allows simultaneous processing of dozens of different objects without utilizing local computational resources. This facilitates decomposition of large objects and parallel processing of all elements, significantly reducing processing time. The primary disadvantage is security concerns, as all data is uploaded to remote servers and could potentially be accessed by third parties.



(a) (b) (c) (d)

Fig. 2. Visual representation of the obtained point clouds: a – Agisoft Metashape, b – 3DF Zephyr, c – RealityCapture, d – LumaAI

Discussion

The results of the experiment demonstrate significant differences in the effectiveness of software for photogrammetric digitization and visualization of complex energy facilities. RealityCapture possesses hybrid algorithms capable of combining different data types (photos + LiDAR), ensuring metric accuracy (1–10 mm), critical for engineering tasks. GPU optimization and distributed computing across RTX cards reduce processing time by 1.3–4 times compared to analogues (Zephyr, Metashape). Adaptive filtering of the spectral characteristics of metals provides resilience to glare (reflective surfaces of metal pipes and insulation). Support for over 50 formats and direct export to Unreal Engine simplify the creation of VR simulators and digital twins. The primary limitation is the complexity of using the software in the Russian Federation, requiring non-standard solutions (changing OS region, VPN), which in turn increases risks for corporate implementation.

LumaAI demonstrates high video processing speed without burdening local resources [20]. NeRF technology enables the reconstruction of occluded zones, and scalability allows for the parallel processing of dozens of objects. Critical disadvantages include planar surface deviations up to 50 mm, the inability to operate without an internet connection or during server overloads, and, most importantly, the risks associated with transferring energy facility data to foreign servers.

Agisoft Metashape showed suboptimal results. However, this may be explained by the characteristics of the object, which did not allow the software's strengths to be revealed, such as Metashape's high potential in multispectral analysis.

The reasons for Meshroom's failure are related to its CPU dependency and lack of optimization for large frame sets. For Pix4D, its orientation towards aerial photogrammetry proved critical – the algorithms are not adapted for terrestrial photogrammetry with dynamic perspectives, encountering problems with glare processing and low textural variation.

Conclusion

The study results demonstrate a significant dependence of the effectiveness of photogrammetric digitization of energy facilities on the choice of software. The experimental findings confirm that RealityCapture provides high accuracy in reconstructing and detailing geometry under the complex conditions typical of energy facilities, including elements with high reflectivity. However, the limited availability of this software in the Russian Federation, caused by sanction-related barriers, creates substantial difficulties for its implementation in the domestic energy sector. Alternative solutions, such as LumaAI, demonstrate high processing speed and good accuracy but are unacceptable for engineering tasks involving classified facilities due to data leakage risks.

The obtained data highlight the urgent need to develop specialized domestic photogrammetric tools adapted to the specifics of the industry and energy facilities, ensuring the required level of information security. Promising directions include:

1. Development of domestic hybrid methodologies combining classical SfM/MVS algorithms with neural network approaches to compensate for their mutual limitations.
2. Creation of solutions emphasizing data security and support for domestic CAD systems.
3. Standardization of accuracy assessment protocols for complex industrial facilities.

An equally important task is establishing a regulatory framework for selecting software used in the digitalization of energy infrastructure, where reconstruction accuracy directly impacts operational safety and the quality of digital twins.

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References

1. A.O. Tolokonskiy, D.G. Kovalionok. Visualization of the Assembly and Control Area of the BREST-OD-300 Reactor FA Using Virtual Reality Technologies (2025). Scientific Visualization 17.2: 23 - 35, DOI: 10.26583/sv.17.2.02
2. A.V. Maltsev. Computer Simulation and Visualization of Wheel Tracks on Solid Surfaces in Virtual Environment (2023). Scientific Visualization 15.2: 80–89, DOI: 10.26583/sv.15.2.07
3. P.Yu. Timokhin, M.V. Mikhaylyuk. Hybrid Visualization with Vulkan-OpenGL: Technology and Methods of Implementation in Virtual Environment Systems (2023). Scientific Visualization 15.3: 7–17, DOI: 10.26583/sv.15.3.02
4. Savelyeva, E.O., Savelyev, I.L., Ivannikov, A.L., & Solodov, S.V. (2025). XR-technologies in intelligent control systems for mining enterprises. Sustainable development of mountain territories, 17(2(64)), 1024-1032. doi: 10.21177/1998-4502-2025-17-2-1024-1032
5. Buyalskiy A.A., Saveliev I.L. Creation of Digital Twins for Energy Facilities. In: *SNK-2024: Proceedings of the LXXIV International Student Scientific Conference of Moscow Polytechnic University*. Moscow, 2024. Pp. 183-187.
6. Bondareva N.A. Graph Neural Networks and Image Verification Tasks // Proceedings of the 33rd International Conference on Computer Graphics and Machine Vision GraphiCon 2023. V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, Moscow, Russia, September 19-21, 2023. P. 317-327. DOI: 10.20948/graphicon-2023-317-327
7. Savelieva E.O., Saveliev I.L. Features of Developing Engineering VR and AR Projects by Student Teams. In: *Laser and Plasma Research and Technologies - LaPlaz-2025: Proceedings of the XI International Conference*. Moscow, 2025. P. 374.
8. Wang Z., Bovik A., Sheikh H., Simoncelli E. Image Quality Assessment: From Error Visibility to Structural Similarity // IEEE Transactions on Image Processing. 2004. Vol. 13, no. 4. P. 600-612. DOI: 10.1109/TIP.2003.819861

9. Mazzonetto I., Castellaro M., Cooper R., Brigadoi S. Leveraging smartphone-based photogrammetry for improved localization and registration of scalp-mounted neuroimaging sensors // Scientific Reports. 2022. Vol. 12. P. 1-14.
10. Homolle S., Oostenveld R. Using a structured-light 3D scanner to improve EEG source modeling with more accurate electrode positions // Journal of Neuroscience Methods. 2019. Vol. 326. P. 1-8.
11. Konopatskiy E.V., Bezditny A.A. Kinematic operation of constructing geometric bodies in point calculus // Bulletin of the South Ural State University. Series: Construction Engineering and Architecture. 2022. Vol. 22, no. 3. P. 79-88. DOI: 10.14529/build220309
12. Valle M.P. de C.A., Gisleni K.V., Gasperin F.F. de, Leal R.L., Silva F.P. da, Bruscato U.M. A proposal for an automated code to convert polygonal meshes of organic forms into CAD-suitable NURBS surfaces // Gestão & Tecnologia de Projetos. 2022. Vol. 17, no. 2. P. 5-17. DOI: 10.11606/gtp.v17i2.166353.
13. Kondybayeva A.B., Solodov S.V. Tricubic Interpolation in Scientific Data Visualization Problems. Wave Electronics and Its Application in Information and Telecommunication Systems Weconf Conference Proceedings, 2019, 8840118DOI: 10.1109/WECONF.2019.8840118
14. Eremina O.Yu., Tomshin E.A. On the methodology of using LiDAR in the environmental monitoring of hazardous production facilities. Occupational Safety in Industry. 2025. No. 5. Pp. 13-18. DOI: 10.24000/0409-2961-2025-5-13-18
15. Gvozdev E.V. Analysis of criteria and methods for assessing organizational risks at explosive and fire-hazardous enterprises. Occupational Safety in Industry. 2025. No. 7. Pp. 48-55. DOI: 10.24000/0409-2961-2025-7-48-55
16. Deryabin S. A., Kondratev E. I., Rzazade Ulvi Azar ogly, Temkin I. O. Digital Mine architecture modeling language: Methodological approach to design in Industry 4.0. MIAB. Mining Inf. Anal. Bull. 2022;(2):97–110. (In Russ.). DOI: 10.25018/0236_1493_2022_2_0_97.
17. Polyanska A., Savchuk S., Dudek M., Sala D., Pazynich Y., Cichoń D. Impact of digital maturity on sustainable development effects in energy sector in the condition of industry 4.0. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2022, (6), pp. 97–103. DOI: 10.33271/nvngu/2022–6/097.
18. Kryukov A., Suslov K., Kryukov A. Calculation of Modes and Electromagnetic Influences of a Long–Distance Ultra–high Voltage Power Transmission to Pipeline Based on Digital Models. Communications in Computer and Information Science, 2025, 1989 CCIS, pp. 3–23. DOI: 10.1007/978–3–031–70966–1_1.
19. Saveleva E.O., Savelev I.L., Ivannikov A.L., Solodov S.V. Prospects of Virtual and Augmented Reality Technology Integration into Intelligent Occupational Safety Management Systems. Bezopasnost Truda v Promyshlennosti = Occupational Safety in Industry. 2025. № 8. pp. 58-62 (In Russ.). DOI: 10.24000/0409-2961-2025-8-58-62.
20. Smelcer C., Erwig M., Metoyer R. A transformational approach to data visualization // Proceedings of the International Conference on Generative Programming: Concepts and Experiences (GPCE 2014). 2014. P. 53-62. DOI: 10.1145/2658761.2658769