Technology-Enhanced Learning in Forensic Science Education: 3D Documentation and Visualization of a Simulated Crime Scene

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Abstract. Current education in criminalistics and forensic disciplines provides opportunities to integrate digital technologies into students' practical training and the solution of model-based professional tasks. This paper focuses on the integration of modern 3D technologies into forensic science education, particularly in the field of crime scene and trace documentation. The theoretical background is based on an analysis of current scientific and professional knowledge concerning the use of 3D laser scanning, photogrammetry, and mobile LiDAR scanning in forensic practice. The practical application is demonstrated on a simulated crime scene documented using these technologies under different illumination levels. The resulting point clouds were processed and compared with a reference scan in the CloudCompare software environment. The results revealed differences among the individual documentation approaches and indicated reduced accuracy of photogrammetry and mobile LiDAR scanning under very low illumination conditions. The generated 3D data were subsequently also used for visualisation of the simulated crime scene in a virtual environment. The paper also aims to highlight the possibilities of technology-enhanced and simulation-based education, through which students of the Faculty of Security Engineering at the University of Žilina can gain practical experience with modern 3D technologies and their application. The acquired knowledge and skills are not limited to crime scene documentation but may also be applied to other professional tasks within the security sciences, for example, to the documentation and analysis of three-dimensional forensic traces, including footwear impressions in snow, sand, and other deformable substrates.

Keywords: 3D Documentation, Forensic Science Education, Crime Scene.

1 Introduction

Crime scene examination is a key procedure for obtaining information about a forensically relevant event, with documentation serving to record the condition of the scene, forensic traces, objects, and their spatial relationships. Because the original scene conditions generally cannot be recreated after the examination, accurate and objective

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documentation is essential. Traditional methods are increasingly supplemented by digital and 3D technologies that provide spatial data for subsequent measurement, analysis, and visualisation [1]. Effective use of these technologies requires appropriate technical knowledge and practical skills. Their integration into forensic science education therefore provides opportunities to connect theoretical knowledge with practical tasks in simulated scenarios, where students can acquire, process, compare, and interpret 3D data while becoming familiar with the capabilities and limitations of individual technologies [2, 3]. The aim of this paper is to demonstrate the integration of terrestrial laser scanning, photogrammetry, and mobile LiDAR scanning into practical criminalistics education. A simulated crime scene documented under different illumination conditions is presented as a case study, including the processing and comparison of the acquired 3D data and their subsequent visualisation in a virtual environment. The paper also highlights the potential for involving students in research-oriented tasks and for applying acquired 3D-related knowledge to broader forensic applications.

1.1 Theoretical Background for the Use of 3D Technologies in Crime Scene Documentation

The development of 3D technologies has expanded the possibilities of documenting forensically relevant events by enabling more accurate spatial recording of environments, objects, and traces [1]. The most commonly used approaches include terrestrial laser scanning, photogrammetry, and mobile LiDAR systems. Their application is generally assessed in terms of accuracy, accessibility, conditions of use, and possibilities for subsequent data analysis. These findings are also relevant to education, as they allow students to become familiar with the principles, capabilities, and limitations of individual technologies.

3D laser scanning creates a point cloud representing the geometry of the documented environment or object and is used mainly for capturing spatial relationships, measurement, and reconstruction [1, 4, 5, 6]. **Photogrammetry** creates 3D models or point clouds from a series of overlapping photographs, while the quality of the output is influenced mainly by the image acquisition procedure, image overlap, surface properties, and illumination conditions [7, 8, 9, 10]. **Mobile LiDAR scanning** uses a sensor integrated into a smartphone or tablet for rapid spatial data acquisition [5, 10, 11]. Compared with professional scanners, it is more accessible, although the accuracy of the resulting data should be assessed according to the intended application [10, 11, 12]. These technologies provide 3D data that can be used for measurement, analysis, comparison, reconstruction, and visualization.

1.2 Relevant Related Studies

Current studies and research demonstrate the increasing use of 3D technologies in crime scene documentation. **Terrestrial laser scanning** enables accurate spatial recording of crime scenes and subsequent measurement, reconstruction, and analysis **[**5, 13]. Recent research has also emphasised the importance of accuracy assessment and quality

control when using terrestrial laser scanners in forensic applications [14]. **Photogrammetry** represents a more accessible approach to creating scaled 3D representations of crime scenes and traces. Reference [8] compared a photogrammetric model of a simulated crime scene with a reference laser scan and reported a maximum linear error of 8 mm. Previous studies have also demonstrated that the quality of photogrammetric outputs is influenced by factors such as illumination, surface properties, image acquisition strategy, and reconstruction procedures [9, 10, 15]. **Mobile LiDAR sensors** integrated into smartphones provide another relatively accessible option for forensic 3D documentation. Reference [11] evaluated the accuracy and repeatability of iPhone-based LiDAR for simulated crime scene documentation, while reference [12] examined its application to shooting trajectory documentation. In [10] mobile LiDAR and photogrammetry were further compared under different illumination and scanning conditions. From an educational perspective, these findings provide a relevant basis for technology-enhanced and simulation-based forensic training. **Simulated scenarios allow students to work with different 3D technologies** and to evaluate how acquisition conditions, accuracy, and data quality influence their suitability for specific forensic tasks [16].

2 3D Documentation of Simulated Crime Scene

As a specific example of integrating modern 3D technologies into students' practical training, experimental documentation of a simulated crime scene was carried out [16]. The aim was to compare selected 3D documentation approaches, assess their capabilities and limitations, and evaluate their applicability in forensic practice. Three technologies were used: **terrestrial laser scanning, photogrammetry, and mobile LiDAR scanning**. Illumination level was selected as the experimental variable, as it was expected to affect mainly photogrammetric and mobile LiDAR outputs. The experiment was conducted in an enclosed garage under stable conditions at **four illumination levels: 10 000 lx, 1 000 lx, 100 lx, and 10 lx** (see Table 1), with a temperature of approximately 15 °C. For each illumination level, approximately **100 images were acquired for photogrammetric processing**. A reference point cloud was created using terrestrial laser scanning, against which the photogrammetric and mobile LiDAR outputs were subsequently compared. This practical task linked simulated crime scene documentation with the acquisition, processing, and evaluation of 3D data while enabling comparison of the individual technologies.

Table 1. Overview of the tested illumination levels and the use of 3D techniques [16].

Illumination level (lx)	3D laser scanner	Photogrammetry	LiDAR
10	✗	✓ (100 images)	✓
100	✗	✓ (100 images)	✓
1000	✗	✓ (100 images)	✓
10 000	✓	✓ (100 images)	✓

2.1 Materials and Methods

The experiment was conducted at a simulated crime scene created in a garage with an area of approximately **24 m²**, where a homicide scenario was staged. Fig. 1 presents a **sketch** (left) and a **plan** (right) **of the simulated crime scene**. Dimensions in the sketch are given in meters, whereas dimensions in the plan are expressed in millimeters. The numbers shown inside circles indicate individual simulated traces.

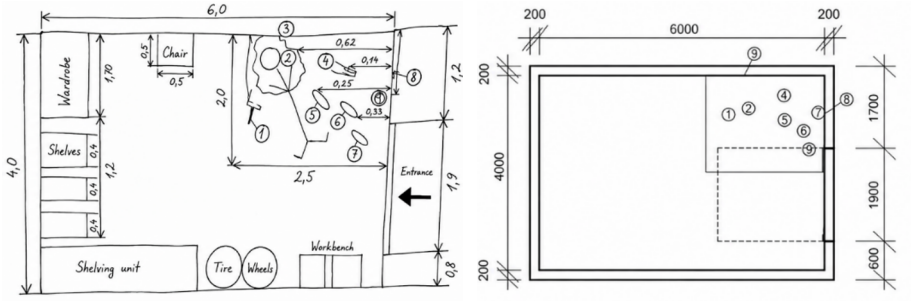


Fig. 1. Sketch (left) and a plan (right) of the simulated crime scene [16].

The experiment involved equipment for **creating and documenting simulated traces, a calibrated steel measuring tape, a lux meter and light sources** (see Fig. 2).

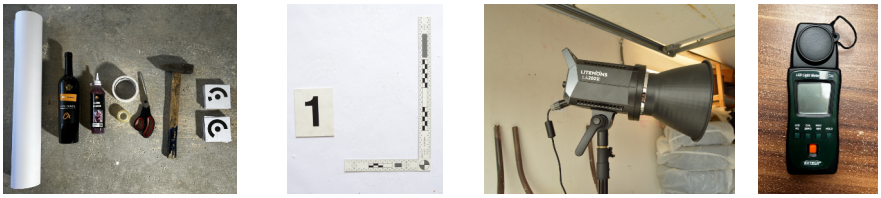


Fig. 2. Experimental equipment [16].

Experimental scanning of the simulated crime scene was performed using a **FARO Focus S70 3D laser scanner**, a **Nikon D3200 digital camera with a NIKKOR 18–55 mm F3.5–5.6G AF-S DX VR II lens**, and the **LiDAR sensor of an iPhone 13 Pro Max**. The acquired data were subsequently processed, visualised, and analysed on an **ASUS TUF Gaming A15** laptop (see Fig. 3).



Fig. 3. Experimental equipment (arranged from left to right): FARO Focus S70, Nikon D3200, NIKKOR, iPhone 13 Pro Max, ASUS TUF Gaming A15 [16].

The acquired data were processed and analysed using **FARO Scene, Agisoft Metashape Professional, and CloudCompare**. **FARO Scene** was used to process, register, and merge the laser scans into a reference point cloud, **Agisoft Metashape**

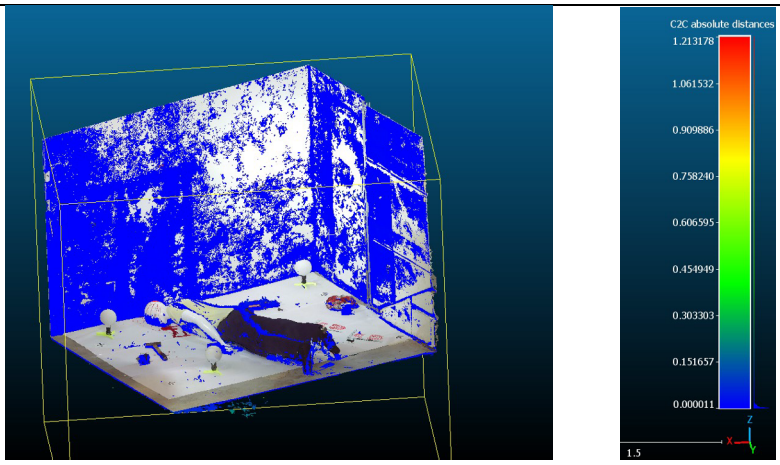
Professional was used to process the photogrammetric data, and **CloudCompare** was used for point-cloud alignment and comparison. Each photogrammetric and mobile LiDAR point cloud was aligned with the reference laser-scan point cloud in CloudCompare using three corresponding points, after which the common comparison area was cropped and **Cloud-to-Cloud (C2C)** absolute distances were calculated. The mean distance represents the average C2C distance from the reference point cloud, while the standard deviation describes the dispersion of these distances around the mean. **3D laser scanning** – the simulated crime scene was documented using a **FARO Focus S70** scanner from five positions. Identical scanner settings were used throughout the measurements (resolution 1/5, scan size 8192 × 3414 points, and point spacing 7.67 mm at a distance of 10 m), with a single scan taking approximately 8 min 40 s. Six reference spheres were used for scan registration; during additional measurements, fixed reference targets on the walls, ceiling, and floor were used when identical sphere placement could not be maintained. The scans were processed and merged in **FARO Scene** to create the reference point cloud used for comparison with the outputs of the other technologies. **Photogrammetry** – photogrammetric data acquisition was carried out under four defined illumination levels listed in **Table 1**. Approximately 100 images were captured for each illumination level according to a predefined acquisition procedure. Images were systematically taken from multiple angles and height levels to ensure sufficient overlap. Images were captured perpendicular to the walls, floor, and ceiling and supplemented by images taken at an angle of approximately 45°, particularly in the corners of the room and around the documented objects. Following camera calibration, the images were processed in **Agisoft Metashape Professional**, where separate point clouds were generated for each illumination level. **Mobile LiDAR scanning** – the third technology applied was mobile LiDAR scanning using an iPhone 13 Pro Max and the **SiteScape application**. Scanning the entire garage took approximately 1 minute and was performed by continuously moving the device through the space. Near the documented objects, the device was moved closer to the surfaces to capture a higher level of detail. Scanning was performed under the same four illumination levels as the photogrammetric acquisition and always immediately after the photogrammetric data collection to maintain comparable lighting conditions. **The resulting point clouds were compared using the same procedure.** The 3D laser scanning documentation process and the simulated crime scene are shown in Fig. 4.



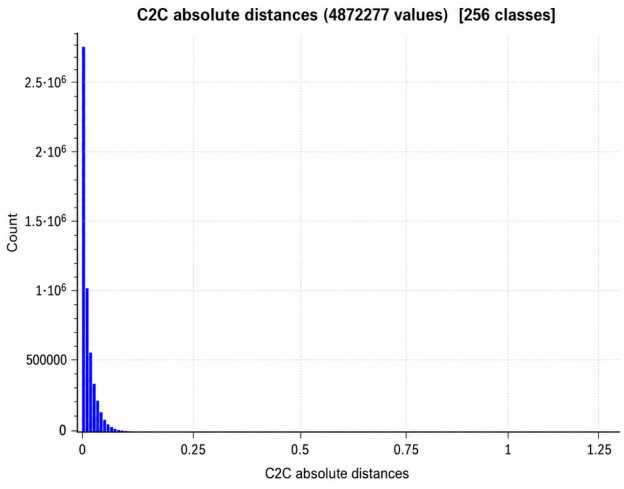
Fig. 4. 3D laser scanning documentation process [16].

2.2 Results

In the results section, attention was focused on comparing the accuracy of the 3D outputs obtained using photogrammetry and mobile LiDAR scanning. The generated point clouds were compared with a reference point cloud acquired using a 3D laser scanner, which served as the reference dataset for the evaluation. CloudCompare software was used for data processing and for assessing deviations between the individual point clouds. The following figures (see Fig. 5) present selected examples of point-cloud comparison, including the CloudCompare software environment. Two representative cases are shown: a comparison between the reference point cloud and the photogrammetric output acquired at an illuminance level of 100 lx, and a comparison between the reference point cloud and the output obtained using the LiDAR sensor of the iPhone 13 Pro Max at an illuminance level of 1 000 lx. Further details are provided in [16].



a)



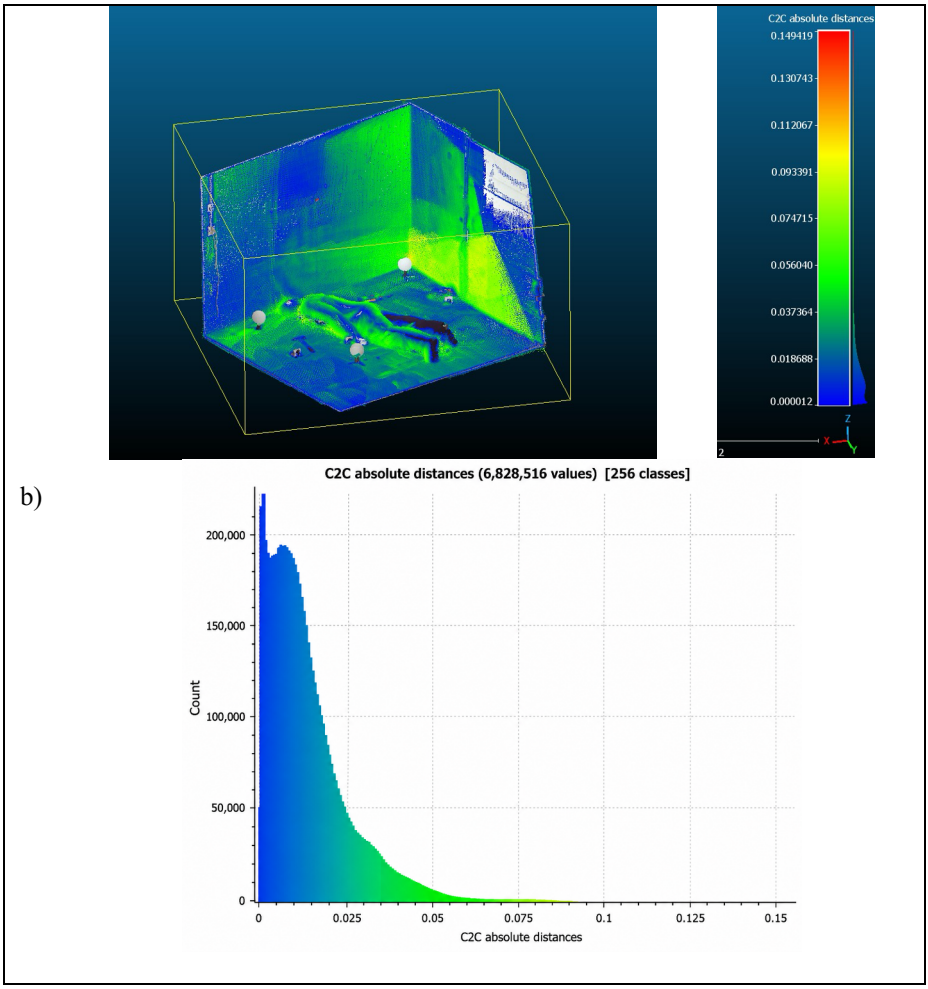


Fig. 5. (a) Comparison of the photogrammetric output with the reference scan and (b) Comparison of the mobile LiDAR output with the reference scan [16].

Based on the results, a summary table (see Table 2) was compiled presenting the comparison metrics for all acquired point clouds against the **reference scan used as the benchmark.** All comparisons were performed in **CloudCompare**. The results presented in Table 2 indicate that, under the conditions of the experiment, illumination level affected the accuracy of the 3D outputs obtained using both evaluated methods. In photogrammetry, the mean distance of points from the reference point cloud increased as the illumination level decreased, with the most pronounced deterioration observed at 10 lx. At this illumination level, the mean distance reached 21.7 mm, representing a substantial increase compared with the other lighting conditions. The standard deviation values varied across the individual illumination levels, with the highest value also recorded at 10 lx.

Table 2. Resulting deviations from the reference scan [16].

	Illuminance level [lux]	Mean distance [mm]	Standard deviation [mm]
Photogrammetry	10 000	5.8	17.3
	1000	7.2	10.0
	100	8.5	13.6
	10	21.7	19.5
iPhone (LiDAR)	10 000	6.1	7.1
	1000	13.8	11.8
	100	13.8	17.6
	10	27.0	20.4

For mobile LiDAR scanning, the lowest mean distance was recorded at 10 000 lx. At 1 000 lx and 100 lx, the mean distance reached the same value, whereas at 10 lx it increased markedly. At the same time, the standard deviation increased as the illumination level decreased. The highest mean distance among all evaluated outputs was recorded for mobile LiDAR scanning at 10 lx, reaching 27.0 mm. Under the conditions of the experiment, the results therefore indicate a pronounced reduction in the accuracy of both photogrammetry and mobile LiDAR scanning under very low illumination, with a higher mean deviation at 10 lx observed for mobile LiDAR scanning. **The mean distances recorded at the individual illumination levels are graphically presented in Fig. 6, the corresponding standard deviations in Fig. 7, and all comparison results are summarised in Fig. 8.**

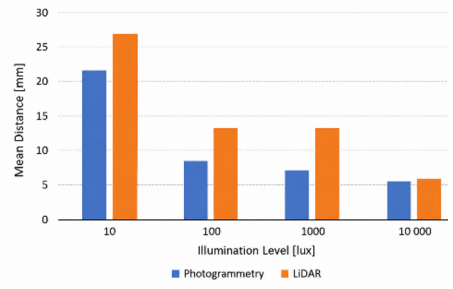


Fig. 6. Graphical representation of the mean distance comparison results [16].

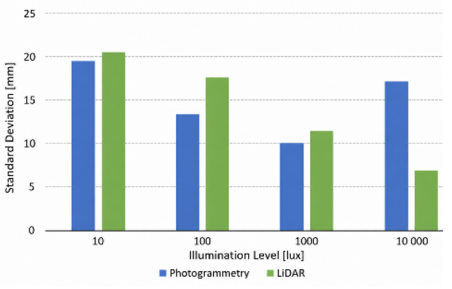


Fig. 7. Graphical representation of the standard deviation comparison results [16].

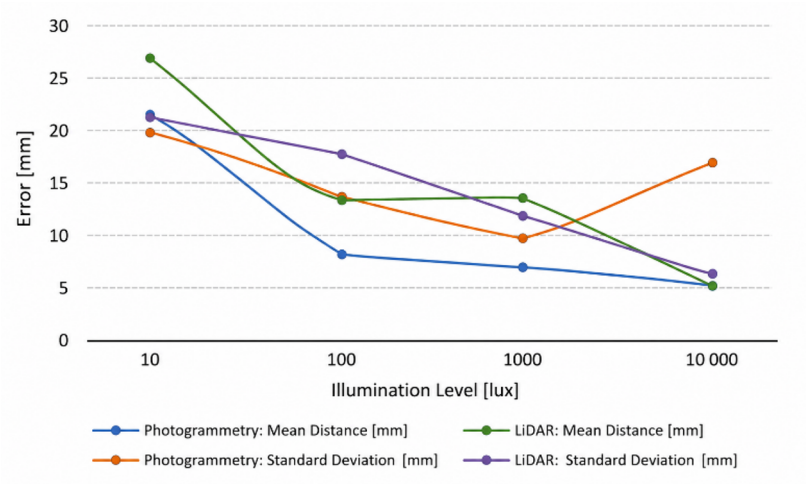


Fig. 8. Graphical representation of all comparison results [16].

2.3 Virtual Reality Visualization of a Simulated Crime Scene

In the final stage of the practical work, the potential use of virtual reality for visualizing the created 3D model of the simulated crime scene was also examined. For this purpose, a **Meta Quest 2** headset was used. The model, created by combining the reference laser scan with photogrammetric data acquired at an illumination level of **10 000 lx**, was processed in **RealityCapture** and **FARO Scene** and subsequently visualized in a virtual environment. The VR environment enabled repeated examination of the documented scene, movement within the reconstructed space, and selected spatial measurements. This application demonstrates the potential for further use of processed 3D data not only in the analysis of documented crime scenes, but also as a **supplementary tool in the practical training of students** (see Fig. 9).



Fig. 9. Demonstration of the use of virtual reality for navigation within the simulated crime scene, including an example of measuring distances between traces [16].

3 Conclusion

The practical example demonstrated the potential of 3D laser scanning, photogrammetry, and mobile LiDAR scanning for documenting a simulated crime scene and for their integration into practical criminalistics education. The evaluated methods differed in accuracy, acquisition time, technical requirements, and sensitivity to acquisition conditions. The results indicated that illumination level influenced both photogrammetric and mobile LiDAR outputs, with the most pronounced deterioration observed under very low illumination. These findings emphasise that the selection of a 3D documentation method should reflect not only its accessibility and speed, but also the required level of accuracy and the conditions under which data are acquired. As the experiment was conducted on a single simulated crime scene, the results should be interpreted as an initial comparative assessment requiring further verification under a wider range of conditions. From an educational perspective, the study demonstrates how technology-enhanced and simulation-based approaches can be incorporated into forensic science education through realistic practical tasks. Students can participate in the complete documentation workflow, from crime scene examination and spatial data acquisition to point-cloud processing, comparison, and interpretation. Importantly, such tasks enable them to compare different technologies directly and to recognise their capabilities, limitations, and suitability for specific forensic applications. The use of simulated crime scenes therefore provides a practical framework for linking theoretical knowledge, current research, and technologies used in forensic practice, while also creating opportunities to integrate student thesis work and research activities into the educational process.

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References

1. Adamová, V., Kubjatko, T., Boc, K.: Možnosti využitia 3D snímacej technológie v kriminalistike. Trilobit 2/2019 (2019).
2. Adamová, V., Šoltés, V., Madleňák, M.: The Connection Between Education in the Field of Criminalistics and Student Research Activities. In: INTED2024 Proceedings, pp. 7748–7757. IATED (2024). doi:10.21125/inted.2024.2071.
3. Adamová, V., Kampová, K., Gajdošíková, T.: The Student as Researcher: A Model of Integrating Students into Scientific Work Through Grant-Funded Projects in the Field of Forensic Sciences. In: ICERI2025 Proceedings, pp. 6807–6817. IATED (2025). doi:10.21125/iceri.2025.1864.
4. Húsková, V., Adamová, V., Boc, K.: Využitie 3D snímacej technológie zaisťovania trasologických stôp v procese kriminalistickej identifikácie. Trilobit 1/2021 – Mladá věda (2021).

5. Galanakis, G., Zabulis, X., Evdaimon, T., Fikenscher, S.-E., Allertseder, S., Tsikrika, T., Vrochidis, S.: A study of 3D digitisation modalities for crime scene investigation. Forensic Sciences 1(2), 56–85 (2021). https://doi.org/10.3390/forensicsci1020008.
6. Luchowski, L., Pojda, D., Tomaka, A.A., Skabek, K., Kowalski, P.: Multimodal imagery in forensic incident scene documentation. Sensors 21(4), 1407 (2021). https://doi.org/10.3390/s21041407.
7. Adamová, V., Šoltés, V., Boc, K.: Dokumentácia trojrozmerných trasologických stôp pomocou aplikácie fotogrametrie blízkeho dosahu. Krízový manažment 21(1), 5–15 (2022). doi:10.26552/krm.C.2022.1.5-15.
8. Ospina-Bohórquez, A., Del Pozo, S., Courtenay, L.A., González-Aguilera, D.: Handheld stereo photogrammetry applied to crime scene analysis. Measurement 216, 112861 (2023). https://doi.org/10.1016/j.measurement.2023.112861.
9. Yu, S.-H., Thomson, G., Rinaldi, V., Rowland, C., Nic Daeid, N.: Development of a Dundee Ground Truth imaging protocol for recording indoor crime scenes to facilitate virtual reality reconstruction. Science & Justice 63(2), 238–250 (2023). https://doi.org/10.1016/j.scijus.2023.01.001.
10. Sheshtar, F.M., Alhatlani, W.M., Moulden, M., Kim, J.H.: Comparative analysis of LiDAR and photogrammetry for 3D crime scene reconstruction. Applied Sciences 15(3), 1085 (2025). https://doi.org/10.3390/app15031085.
11. Kottner, S., Thali, M.J., Gascho, D.: Using the iPhone's LiDAR technology to capture 3D forensic data at crime and crash scenes. *Forensic Imaging* 32, 200535 (2023). https://doi.org/10.1016/j.fri.2023.200535.
12. Chase, C.E., Liscio, E.: Technical Note: Validation of Recon-3D, iPhone LiDAR for bullet trajectory documentation. *Forensic Science International* 350, 111787 (2023). https://doi.org/10.1016/j.forsciint.2023.111787.
13. Esposito, M., Sessa, F., Cocimano, G., Zuccarello, P., Roccuzzo, S., Salerno, M.: Advances in technologies in crime scene investigation. Diagnostics 13(20), 3169 (2023). https://doi.org/10.3390/diagnostics13203169.
14. Gregg, M., Muralikrishnan, B., Shilling, M.: Toward a documentary standard for performance testing of terrestrial laser scanners used in forensic practice: A statistical procedure to assess change in instrument precision. Journal of Forensic Sciences 71(2), 1023–1031 (2026). https://doi.org/10.1111/1556-4029.70256.
15. Ujvári, Z., Metzger, M.: A fotogrammetria kriminalisztikai alkalmazása – tudományosan megalapozott módszerek fényképezőgép segítségével történő 3D képrögzítéshez. Rendőrségi Tanulmányok, Special Issue, 78–220 (2024). https://doi.org/10.53304/RT.2024.ksz.02.
16. Miniariková, G.: 3D snímkovanie aplikované na dokumentáciu miesta činu. Master's thesis, University of Žilina, Faculty of Security Engineering, Žilina (2024).

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