Virtual Reality as a Collaborative Tool for Digitalised Crime Scene Examination

Rinaldi, Vincenzo; Hackman, Lucina; Nic Daeid, Niamh

Published in:
Extended Reality

DOI:
10.1007/978-3-031-15546-8_14

Publication date:
2022

Citation for published version (APA):
Rinaldi, V., Hackman, L., & Nic Daeid, N. (2022). Virtual Reality as a Collaborative Tool for Digitalised Crime Scene Examination. In L. T. De Paolis, P. Arpaia, & M. Sacco (Eds.), Extended Reality: First International Conference, XR Salento 2022, Lecce, Italy, July 6–8, 2022, Proceedings, Part I (Vol. 13445, pp. 154-161). (Lecture Notes in Computer Science; Vol. 13445). Springer . https://doi.org/10.1007/978-3-031-15546-8_14

Rinaldi, V, Hackman, L & Nic Daeid, N 2022, Virtual Reality as a Collaborative Tool for Digitalised Crime Scene Examination. in LT De Paolis, P Arpaia & M Sacco (eds), Extended Reality: First International Conference, XR Salento 2022, Lecce, Italy, July 6–8, 2022, Proceedings, Part I. vol. 13445, Lecture Notes in Computer Science, vol. 13445, Springer , pp. 154-161, 1st International Conference on eXtended Reality , Lecce, Italy, 6/07/22. https://doi.org/10.1007/978-3-031-15546-8_14

Virtual Reality as a collaborative tool for digitalised crime scene examination

Vincenzo Rinaldi [1][0000-0003-4773-0732], Lucina Hackman [1][0000-0002-4457-9187],
Niamh NicDaeid [1][0000-0002-9338-0887]

[1] Leverhulme Research Centre for Forensic Science, University of Dundee, Dundee, UK
`{VRinaldi001, LHackman, NNicdaeid}@dundee.ac.uk`

Abstract. Crime scene investigation is a multidisciplinary response that involves the identification and securing of physical and trace material that may have evidential value. In this context, accurate documentation of the scene(s) is fundamental, when subsequent analysis is required for comparison and evaluative purposes.

This technical note reports a virtual reality framework developed in Unity 3D targeting a low-cost Virtual Reality (VR) head-mounted display (HMD), which enables the exploration of virtualized crime scenes and supports collaborative investigation through an online shared repository of 3D reconstructions. The system is agnostic at the source, implying that several types of 3D imaging sensors can provide recording of the scenes. Data are presented via an immersive virtual-roaming VR application to enhance spatial perception and telepresence. The virtualized environment is accompanied by original photographs and reference information, enabling validation and contextualization of the three-dimensional spatial data. The developed framework was employed in the context of a training operation spread between Scotland, UK and Denmark, demonstrating the feasibility of the deployment of the platform independent of location at the early stages of a forensic investigation.

Keywords: Virtual reality; Forensic science; Crime scene investigation; 3d reconstruction, Collaborative systems, Multimodal interfaces

1 Introduction

The analysis of a crime scene is cross-functional work that requires multi-skilled teams to cooperate often with limitations due to environmental restrictions and temporal constraints. In complex cases, first responders and investigators may seek help from other forensic science experts [1]. This carries the inevitable need to enlarge the pool of specialized personnel operating at the crime scene whilst, at the same time there is a need to cause minimal contamination of the scene through the presence of these individuals. Streefkerk et al. [2] also report on limitations hindering staff's ability to attend crime scenes in a timely manner, such as *"officers availability, proximity to the incident and incident priority"*. In addition, other exceptional circumstances, for example, the Covid-19 pandemic, can also hamper the expert's mobility and impact their availability to attend at the scene. This highlights both the need, and the opportunity, to develop a system that enables experts to remotely perform a rapid inspection of the scene, providing immediate support to first responders before the experts may be able to reach the site themselves.

In the context of incident response, early documentation and evaluation of the scene are vital. Techniques such as sketching, photography, and videography are traditional and trusted methods of site processing [3]. In the last decade, new technologies and sensors began to emerge which supplemented the traditional approach to crime scene documentation, including but not limited to, photogrammetry and scanners incorporating different light sources [4][5]. The data collected with modern imaging devices hold multifold information, which is still mostly accessed through traditional screens displaying 3D content through 2D devices, thereby missing depth, understanding and spatial perception.

Previous works reported in the scientific literature on the use of immersive headsets as a means of navigation of virtualized crime scenes, mainly target witness interrogation [6] and post-analysis incident reconstruction [7][8], however to the knowledge of the authors, no previous work has explored the integration of a VR tool to facilitate decision making at the early stages of a forensic investigation.

In this work, we wanted to assess the feasibility of virtualizing a crime scene enabling visualization of the 3D data in a collaborative Virtual Environment (VE) during the initial phase of an investigation. We introduce a framework to create a reproduction of the incident locus and have developed a Crime Scene VieweR (CSVR) application to enable navigation of the virtual spaces, whilst also addressing several issues which render current commercial 3D viewers unsuitable for forensic employment. A calibration tool component was devised to complement the viewer in facilitating scale accurate calibration of the 3D models. A separate component enhances reconstructions produced using photogrammetry-based methods allowing automated incorporation of the photographs that were the source for this modelling method. A dedicated repository was deployed to ensure secure data access, using security certificates that guarantee the authenticity and reliability of the communicating parties. These components grant secure access of scale correct models to the developed application. Therefore, once the initial images of the crime scene have been captured, the user can perform remote analysis of an accurate digital representation of the scene without accessing areas at risk of contamination. A key advantage of creating a virtual space is that it allows the experience to be shared amongst multiple devices, providing live collaboration amongst professionals and scientific experts located at different locations.
We present a full proof of concept demonstration carried out between Scotland in the UK and Denmark that adopted the proposed framework and demonstrated the feasibility of the process. An analysis of the benefits and drawbacks is presented, with an outlook on the integration of new measurement and presentation tools into the suggested process.

2 Materials and methods

The whole pipeline of integration of the CSVR system consists of two clear phases, as seen in Figure 1, the data preparation phase, and the data utilization phase.

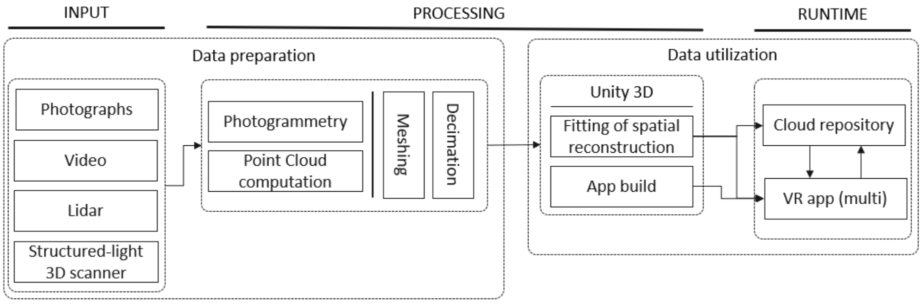

Fig. 1. Workflow of the process that enables full visualization of the scene.

The data preparation phase concerns the documentation of the site using one (or a combination of) digitalization technique(s). The availability of equipment, the skills of those involved, and environmental factors (i.e. space and light conditions) typically determine the choice of the imaging method utilised. The tools listed at the first stage of the data preparation phase, composing the ‘Input’ step in Figure 1, typically produce data in a raw format requiring further processing before utilisation in any application. Most commercial 3D processing software allow refinement and conversion of unprocessed data into formats suitable for visualization or integration in any of the 3D engines commercially available. This step is shown in Figure 1 as the initial stage of the processing, in which cleaning of the data takes place, commonly removing outliers and low-confidence points. Then, the creation of meshes and decimation of triangles produce a simplified model, to offer the highest quality whilst considering the performance limits of the target platform.

In our tests, imaging of scenes using several 3D imaging tools including photogrammetry, videogrammetry and Matterport 3D were undertaken, and the data produced was successfully used to render the environments as textured meshes. When using a Terrestrial Laser Scanner and a Handheld Mobile Scanner, spatial data was registered as point clouds. To achieve smooth visualization, point clouds were converted into 3D models using the surface remeshing tool of the software CloudCompare [9].

It should be noted that even when imaging the same environments, computation for the point clouds required longer times compared to the tools natively outputting meshed surfaces. Furthermore, methods applying format conversion [10] introduce approximations whose uncertainty should be estimated, although this topic is beyond the scope of this paper.

The last part of the processing of the data phase takes place in the 3D engine. The CSVR was developed in the game engine Unity 3D, targeting the OpenXR open standard and deployed on the HMD Meta Quest 2. Given the resources at hand, the extent of the virtualized space and the resolution of data, the 3D models were cleaned up by removing redundant information, and a dedicated shader was created to meet the hardware requirements of the platform of choice [11]. To enable multi-platform support, a modified version of the software targets computers with traditional 2D displays.

The fitting of the spatial reconstruction models (i.e. calibration and the integration of source information) constitutes the first part of the data utilization phase. This operation ensures the correct alignment of the 3D models, as they often lack information regarding scale and orientation, due to a change in the reference system at import time. We tackled this critical issue by creating a tool for systematic rigid transformation and scale calibration. Firstly, three points in space are declared for the alignment (Fig.2). Optionally, the alignment points determine the vertical offset to match the height of the virtual floor. Secondly, two supplementary positions are assigned to define a scalebar of reference.

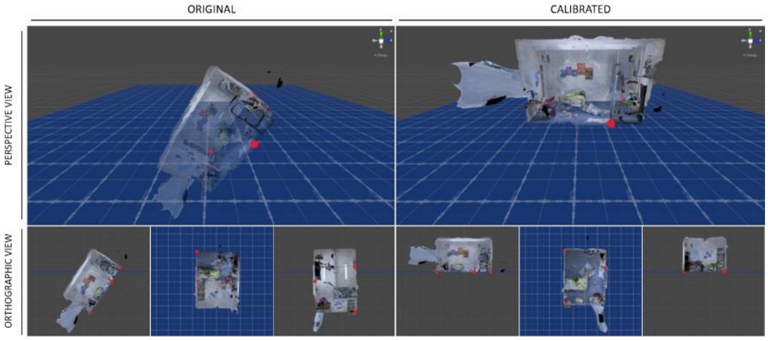

Fig. 2. Model calibration tool: exocentric view (above), lateral, top, and frontal views (below). The red dots highlight the selected alignment points.

Outliers in the source data, occlusion at scan time, and imprecise sensor calibration can often produce artefacts in the geometry. As a result of this, the user may require the provision of supplemental data to validate or disprove the reconstruction. In the case of photogrammetry, for example, software such as Agisoft Metashape can be utilised to embed the position of input photographs that generated the 3D geometry into the exported model as individual entities. We exploit this information by rendering the photographs as floating pictures. A placemark for each photograph reveals the location of the camera that was used to take the images (Fig.3). The user can grasp and handle photographs as physical stills and validate the 3D reconstruction by examining the source images, also identifying artefacts and areas lacking detail.

Fig. 3. View of a reconstructed site with source photographs. The displayed photo was selected by the user for inspection.

After the model(s) positioning, a catalogue bundles the fitted data with descriptive properties, such as registration method, generation setting, etc. Ultimately, the arranged data is published on a dedicated server accessible only to the signed application.

CSVR Multi-users instance

The Unity 3D offers several tools to enable multi-user experiences. The client-server feature of CSVR allows the users to share the virtual environment (Fig. 4).

Fig. 4. First-person snapshot of a reconstruction shared amongst three users.

Each user session starts with the selection of the role. The designated host user begins the session by creating a host session. Then, the host shares the connection information with other users, who can join the shared virtual space. Both parts, server, and host, can run on any supported platforms. The external cloud repository ensures the participants of the joint space can share the same version of the catalogue bundling the reconstructions (Fig. 5).

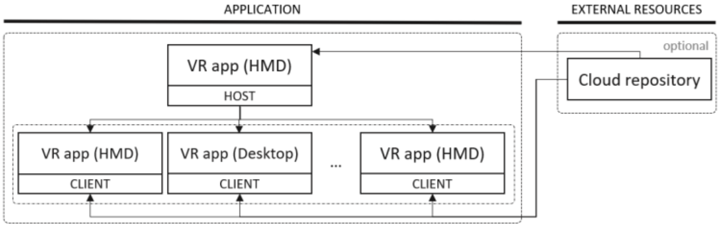

Fig. 5. Distributed Client-Server application structure with optional cloud catalogue.

In the case of the unavailability of a cloud repository, an alternative version of the catalogue can be embedded into the application, storing the data locally on the device, ensuring privacy in scenarios where a secure connection is not guaranteed.

A unique identifier is associated with each 3D reconstruction and assigned prior to the bundle creation phase. This enables each instance to exchange packets containing only an operation and object identifier, limiting the amount of data to transfer during virtual roaming. The reason for this design choice is twofold. Firstly, the data exchanged between the application instances is text-only, avoiding sensitive data transfer when using unsecured connections. Secondly, the framework addresses use at unknown locations without assumptions about the available bandwidth, therefore, small message exchange has been preferred to the peer-to-peer distribution of files, i.e. 3D models and source photographs.

3 Test of the Concept

A pilot test was performed using photogrammetry, during a collaboration between the University of Dundee and The Danish National Police Forensic Centre [12]. The main goal of the work was to evaluate the feasibility of the developed solution, focusing on the total deployment time from the beginning of the data collection to the availability of the final 3D render, quality of output and practicality of the distributed approach. The approach is illustrated in Fig. 6, and the time taken for each task is shown in Table 1.

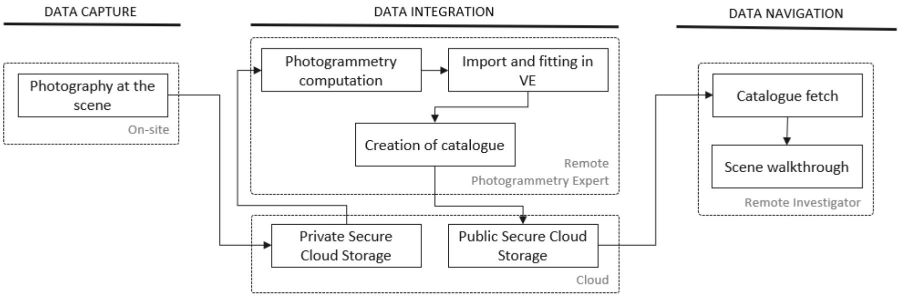

Fig. 6. Dataflow diagram with corresponding domains.

Table 1. Results of processes and times.

Process	Data capture (a)	Transfer (b)	Photogrammetry (c)	Fitting (d)	Upload (e)	Download (f)
Time	1h 18m	23m	29m	10m	<1m	<1m
Size	160 images	1.87 GB	55 MB	-	290 MB	290 MB
Hardware capacity	Intel®Core™i7–7800X CPU @3.50 GHz, 6 cores, 12 threads, 64.0 GB RAM. Internet bandwidth (b), (e), (f): 11Mbps					

A member of staff without specialized training in photography or crime scene investigation performed the documentation of a mockup fire crime scene in Denmark (a) using a standard operating procedure devised by the research team. Photography was undertaken using a Canon EOS 5D Mark III, a traditional 22.3 megapixels full-frame camera The timestamps of the first and last photos were used to obtain the time taken for this task. Once imaging was completed, the photographs were extracted from the memory card to a laptop, and a copy of the data was uploaded to a remote server using a secure cloud repository (b). Once uploading to the cloud repository was complete, a remote technician in Scotland, UK retrieved the data from the server and computed the photogrammetric model and texture of the room using the Agisoft Metashape software [13] version 1.6.3.10732 (c). The settings selected for the mesh generation were the ‘Depth map generation’ method with a ‘High’ level of detail for both alignment and mesh generation, subsequently decimating the model down to 750 thousand faces. Then, preparation and data utilization were conducted as described in the previous section (d). At this stage, a digital catalogue containing the 3D reconstruction was bundled and uploaded to a server (e), exposing a public endpoint of the repository only accessible to the signed CSVR application.

Lastly, a remote fire investigator located in Scotland, UK tested the CSVR application. The bootstrap phase of the client checked against the repository, downloading the latest version of the catalogue (f), enabling the expert to perform a walkthrough of the digitalized indoor environment. The total time required for data acquisition, computation, and sharing was 142 minutes from the beginning of the operations.

The remote investigator accessed the site via a virtual walkthrough using a Meta Quest headset. Performing a solo survey of the virtualized room, the level of detail of the geometry allowed them to assess the scene, indicating areas of investigative interest. Positive feedback was given regarding the texture quality, revealing details such as a broken glass of a window and a visible spider's web. During this test, the user appreciated the quality of the virtual model. Further tests regarding the knowledge transfer and user experience are part of future research planned.

4 Conclusions

We have shown the basic procedure required to perform rapid crime scene virtualization using commercially available equipment. A framework to enable the digitalization of the sites has been presented, and a dedicated multi-platform application to perform intuitive navigation of the reconstructed environment is described.

We evaluated the feasibility of the developed approach during a simulated crime scene investigation, to demonstrate the capability of current state-of-the-art methods and tools that can enable remote experts to experience the scene whist also enhancing telepresence. The devised framework has demonstrated that an accurate model of an indoor scene can be obtained at the early stages of a crime scene investigation, allowing a remote expert to perform preliminary analysis and decision making using this software as a tool. Expansion of the tools available in the application is planned, to enable users to perform accurate measurements, add annotations and record actions. We expect to enlarge the pool of 3D imaging techniques, such as commercially available Time-of-Flight sensors and neural rendering models. We also wish to perform more in-depth tests regarding the uncertainty estimation of the reconstructions.

5 References

[1] M. D. Merck, “Crime Scene Investigation,” *Vet. Forensics Anim. Cruel. Investig.*, pp. 17–35, 2013, doi: 10.1002/9781118704738.ch2.

[2] J. W. Streefkerk, M. van Esch-Bussemakers, and M. Neerincx, “Context-Aware Team Task Allocation to Support Mobile Police Surveillance,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 5638 LNAI, 2009, pp. 88–97.

[3] J. T. Fish, L. S. Miller, M. C. Braswell, and E. W. Wallace, “Crime scene investigation,” *Crime Scene Investig.*, pp. 1–433, 2013, doi: 10.4324/9781315721910.

[4] G. Sansoni *et al.*, “Scene-of-crime analysis by a 3-dimensional optical digitizer a useful perspective for forensic science,” *Am. J. Forensic Med. Pathol.*, vol. 32, no. 3, pp. 280–286, 2011, doi: 10.1097/PAF.0b013e318221b880.

[5] G. Galanakis *et al.*, “A Study of 3D Digitisation Modalities for Crime Scene Investigation,” *Forensic Sci.*, vol. 1, no. 2, pp. 56–85, 2021, doi: 10.3390/forensicsci1020008.

[6] T. Sieberth, A. Dobay, R. Affolter, and L. C. Ebert, “Applying virtual reality in forensics – a virtual scene walkthrough,” *Forensic Sci. Med. Pathol.*, vol. 15, no. 1, pp. 41–47, Mar. 2019, doi: 10.1007/s12024-018-0058-8.

[7] J. Wang *et al.*, “Virtual reality and integrated crime scene scanning for immersive and heterogeneous crime scene reconstruction,” *Forensic Sci. Int.*, vol. 303, 2019, doi: 10.1016/j.forsciint.2019.109943.

[8] L. C. Ebert, T. T. Nguyen, R. Breitbeck, M. Braun, M. J. Thali, and S. Ross, “The forensic holodeck: an immersive display for forensic crime scene reconstructions,” *Forensic Sci. Med. Pathol.*, vol. 10, no. 4, pp. 623–626, 2014, doi: 10.1007/s12024-014-9605-0.

[9] “CloudCompare (version 2.12.0) [GPL software].” 2021, [Online]. Available: www.cloudcompare.org.

[10] V. Estellers, M. Scott, K. Tew, and S. Soatto, “Robust Poisson Surface Reconstruction,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 9087, 2015, pp. 525–537.

[11] “Performance and Optimization, Oculus Developers,” 2022. https://developer.oculus.com/documentation/unity/unity-perf/.

[12] V. Rinaldi, N. Nic Daeid, S. Yu, B. Thomsen, and E. Ljungkvist, “Udgård 2021 Raw Dataset,” 2021. [Online]. Available: https://www.doi.org/10.15132/10000174.

[13] “Agisoft Metashape.” [Online]. Available: https://www.agisoft.com/.