Reverse Engineering from 3D optical acquisition: application to Crime Scene Investigation

G. Cavagnini, M. Scalvenzi, M. Trebeschi & G. Sansoni
Laboratory of Optoelectronics, University of Brescia
via Branze 38, Brescia I-25123, Italy

ABSTRACT: This paper presents the activity aimed at testing the use of 3D optical instrumentation for the contact-less acquisition of crime scenes. The main goal of the work is to assess the feasibility of using a commercial close-range 3D digitizer, designed for industrial and standard reverse engineering applications, to accomplish the 'in field' documentation of crime scenes. The three cases of study we present show the high potential of these techniques and represent a valuable example of interdisciplinary cooperation among different professional people: the criminologist, the police officer, the medical examiner and the engineer.

1 INTRODUCTION

Crime scene investigation is a highly complex activity, that recently has known a radical and decisive development thanks to the contributions of techniques coming from a number of different disciplines.

The first, and perhaps the most critical, phase of criminal investigation is represented by the walk trough of the crime scene. The objective of this task is to collect all useful evidences for the reconstruction of the scene and of the dynamics of the event, according to precise protocols and applying appropriate measurement techniques (James 2003). These operations should offer a complete, non invasive and objective documentation of the scene and should supply a valid base of investigation for subsequent surveying. Classical techniques are inadequate to completely satisfy these requirements. For example, photographs, tapes and sketches can only provide a bi-dimensional description of the scene, thus resulting into a decreased level of completeness of the representation. The use of standard rulers or yardsticks to measure distances is characterized by a limited level of accuracy and can contaminate the scene, due to the contact nature of the measurement. Those kinds of relief also have the disadvantages of being dependent from the ability of the operator and of being time consuming and highly subjective (Thali 2003).

The techniques of photograph stitching and virtual reality (deduced from the direct measurement of the scene and from suitable elaboration by using 3D-Modeling software) tried to go over these lacks, but the 3D representation that they provide is actually deriving from a reinterpretation of natively 2D data. The use of photogrammetry has produced considerable results in a number of applications, such as in the measurement of wounds in 3D incident reconstruction. However it does not represent a widely applicable solution due to its limitations in restituting complex free-form surfaces and to the partially-contact nature of survey (Mueller 2003).

Finally, the above mentioned approaches do not offer the multi-resolution representation of the scene, i.e. the capability of adapting the measurement resolution to the dimension, the complexity, and the significance of the elements that must be acquired. This characteristic is of crucial relevance in view of obtaining a unique, digitally-storable, dense, objective representation of a crime scene that could supply both a 3D interactively navigable virtual scenario as well as a metrically significant archive of the evidences of the scene.

3D optical contactless digitizers can represent a suitable mean to overcome the previously described limitations, thanks to the following aspects: (i) the capability of performing contactless measurement of surfaces, (ii) the portability, (iii) the roughness and the efficiency in terms of the measurement speed.

3D optical digitizers are now available on the market under three major classes, depending on the measurement range: (i) long-range instruments, (ii) medium range instruments, and (iii) short range instruments. The focus of these article is mainly pointed on the third class of instruments, and in particular on those systems based on optical triangulation, both in the passive and in the active form (Blais 2003, Chen et al. 2000). They are characterized by a remarkably high resolution of the acquisition, over a measurement ranges spanning from some centimetres to fractions of meter, for single-view acquisition, to some meters for multi-view acquisition.

So far, they have been employed in forensic medicine applications (Thali et al. 2000-2003, Buschweiler et al. 2003, Banno et al. 2004, Goos et al. 2006, Park et al. 2006) for the 3D documentation of small objects (such as skin, wound and bone injuries). However, at our knowledge, they have not yet been regarded as useful tools for the measurement during the initial walk-through of the investigation step.

In this work, we wanted to assess the feasibility of using a commercial close-range 3D digitizer, based on active optical triangulation, to accomplish the 'in field' documentation of crime scenes. The instrument is the laser stripe scanner Vivid 910 digitizer (Konica Minolta, Inc). It was considered a good candidate for the described application since it is accurate, portable, easily configurable, fast and able to perform the measurements over an extended range.

2 THE OPTICAL 3D DIGITIZER

The optical 3D digitizer is the Konica Minolta Vivid 910 shown in Figure 1 (http://www.konicaminolta-3d.com). The principle of measurement is based on laser triangulation. The object is scanned by a plane of laser light coming from the Vivid's source aperture. The plane of light is swept across the field of view by a mirror, rotated by a precise galvanometer. This laser light is reflected from the surface of the scanned object. Each scan line is observed by a single frame, captured by the CCD camera. The contour of the surface is derived from the shape of the image of each reflected scan line. The entire area is captured in 2.5 seconds (0.3 seconds in FAST mode), and the surface shape is converted to a lattice of over 300,000 vertices (connected points). A polygonal-mesh is also created with all connectivity information retained, thereby eliminating geometric ambiguities and improving detail capture. A brilliant (24-bit) color image is captured at the same time by the same CCD.

Figure 1: The optical digitizer Minolta Vivid 910

The system is rugged, portable, and extremely compact. It can be mounted on a tripod and properly oriented into the measurement volume to optimize the acquisition view point. It is equipped with three lenses, denoted as WIDE (8mm), MIDDLE (14mm) and TELE (25mm) focal lengths. They increase the range of variability of the measurement parameters and allow the system to easily adapt to the acquisition problem. One of the main advantage of the instrument is that it doesn't require a phase of calibration: this characteristic is particularly relevant in the presented study cases, in which adaptability and capability of rapidly varying the measurement setup is often crucial.

Typical values of the measurement parameters are listed in Table 1.

Focal lengths	FOV (mm)	WD (mm)	Zrange (mm)	Rz (mm)
Wide	1000x1000	2000	1000	0.65
Middle	600x450	1000	500	0.3
Tele	140x100	600	200	0.13

Table 1: Typical values of the measurement parameters. FOV: Field of View, WD: Working Distance, Zrange: Range of measurement in the perpendicular direction with respect to the lens, Rz: Measurement resolution.

3 OVERVIEW OF THE MEASUREMENT TECHNIQUE

The process of measurement and data elaboration consists of the following tasks:

1. The acquisition of the point clouds. To accomplish digitization of complex scenarios it is necessary to perform multiple acquisitions from different point of views and with different degrees of detail in order to completely acquire the different areas.
2. The multi-view registration. It consists in the alignment of the set of the captured point clouds into a common reference frame. The module ImAlign, from the suite of software tools of Polyworks, (InnovMetric, Ca) accomplishes this task (http://www.innovmetric.com).
3. The creation of the triangle-mesh. The 3D data of the point cloud are merged into a model that includes information about the topological contiguity of the points by performing a tessellation. This phase is performed by the use of ImMerge module of Polyworks.
4. The editing of the polygon model. The model can be elaborated to decrease the noise influence, reshape those parts that have not correctly been acquired, extract point-to-point distances, extract sections, calculate areas, render the 3D representation for further VMRL interaction, and control the model

from the topological point of view, for prototyping applications. The module ImEdit is used for the editing while the module ImInspect allows to extract measurement.

4 THE CASES OF STUDY

The digitizer was used to accomplish the acquisition of three crime scenes. The first one was a simulated homicide, organized by the Polizia Scientifica of Bologna in the frame of the ‘CrimeLab 2006’ italian project. The second one was a real crime scene, i.e. the discovery of a corpse buried sixteen years ago in a wood-land near Milan (Italy).

Both these scenes were characterized by the use of 3D instrumentation during a ‘in-field’ operation, collaborating with the personnel of the police and forensic sectors, facing a real (or real-like) context of a crime scene and experimenting critical operative conditions. The third one was the acquisition of a broken, and then reconstructed, human skull in order to realize a prototype for legal medicine studies.

4.1 *Study case 1: the simulated crime scene*

The first application in which we experimented the acquisition of a crime scene-like context was in occasion of the ‘CrimeLab 2006’ activity, organized by the Polizia Scientifica of Bologna whose aim was to prepare a didactic movie that showed what happens in practice on a crime scene after its discovering.

The dynamics of the event was supposed as follows: the victim was killed after dinner, at home, in the living-room. The offender shot four cartridges without hitting her. Hence he stabbed her at dead by using a paper-knife.

Figure 2 – The victim lying on the sofa in the living-room

The documentation steps were accomplished by professional police officers and medical examiners, following the protocols used in real cases. Thanks to their cooperation, we were able to locate the most significant evidences and to acquire them.

The central element of the scene was represented by the victim shown in Fig. 2, whose acquisition was made by using the three different configurations of the digitizer reported in Table 1. We obtained, by using the wide-range setup, the 3D models of the whole body (Fig. 3). It was used to extract a number of measurement, such as distances, areas and perimeters. In Fig. 4 an example of point-to-point measurement is shown. We also performed, by using the middle and the close-range configurations, the acquisitions on relevant details, like the wound on the breast of the victim, shown in Fig. 5 and zoomed in Fig. 6. The high level of detail was very useful in the documentation of the skin wound. Fig. 7 is a plot of a section created on the mesh, that allows us to appreciate the quality of the measurement.

Figure 3: The 3D model of the victim (depth plus RGB colors).

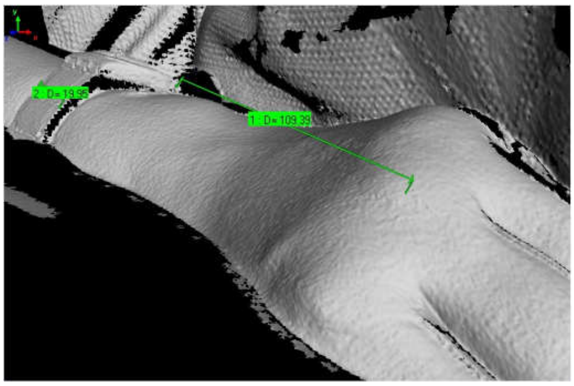

Figure 4: An example of a distance measurement extracted from the model.

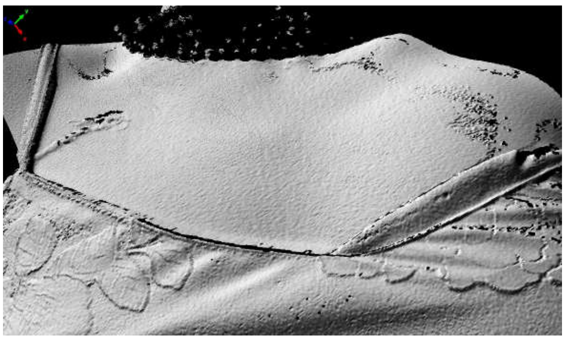

Figure 5: High resolution acquisition of the breast of the victim. The wound is visible on the left.

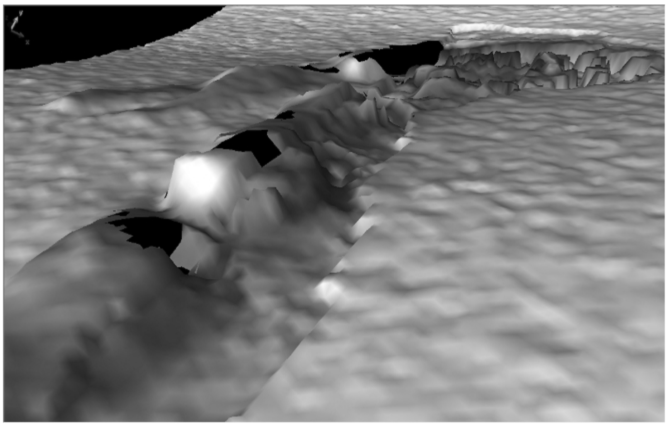

Figure 6: Zoom on the skin wound.

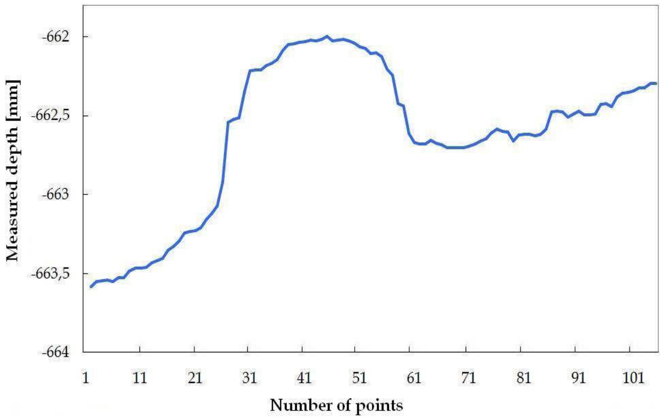

Figure 7: Plot of a section created on the mesh.

We also acquired other important items of the scene, like the bloody paper-knife on the carpet (Fig. 8) and the hole left by a bullet in the book behind the sofa (Fig. 9). Some particular elaborations of this last task are presented, such as the measurement of the diameters of the hole (Fig.10) and the “navigation” of the model, both by zooming and orienting the point of view (Fig. 11). The direction of the cartridge is well defined by the rendered shape, and the measurements reveal that a 9mm projectile was used.

The acquisition work for this first task was accomplished in less than one hour on the scene itself, while the data alignment and editing were completed in laboratory.

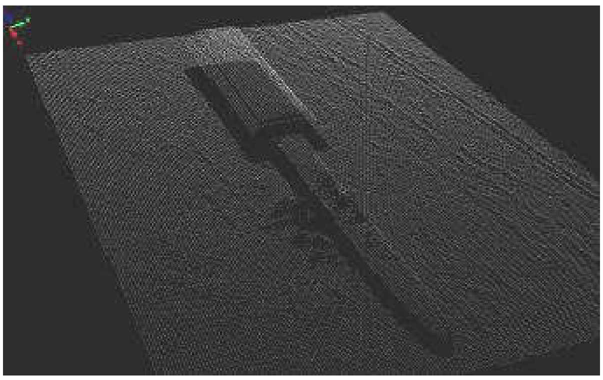

Figure 8: Point cloud of the bloody paper knife on the carpet.

Figure 9: Documentation of the cartridge hole: 3D image of the books behind the sofa. The red circle evidences the area of the hole.

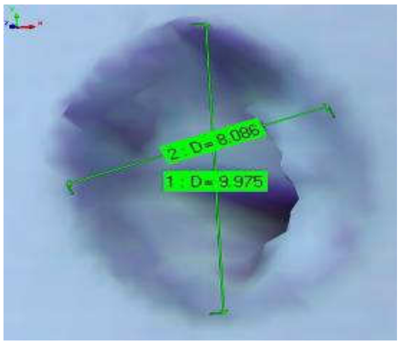

Figure 10: Measurement of the hole dimension.

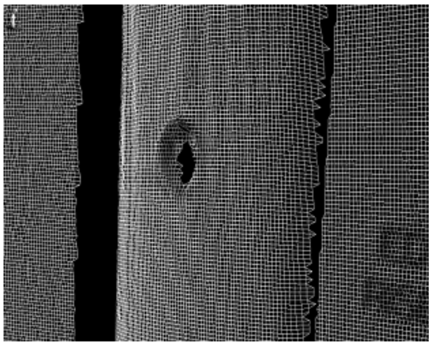

Figure 11: Wireframe representation of the area surrounding the hole.

4.2 *Study case 2: the real crime scene*

The second experiment was performed in occasion of the discovery of a corpse buried sixteen years ago in a wood-land near Milan: here, we could exploit the know-how previously acquired to a real context. The 3D measurement of the scene should not slow down the activities of the police officers and of the technicians and should perform the acquisitions at the maximum possible completeness, in order to freeze the scene before the removal of the corpse. In particular, the objective was to document the position of the skeleton and to gauge the skull of the victim.

The corpse was lying in a hollow, 30 cm deep, and was covered by a oilcloth (Fig. 12). The skull was partially disrupted by the excavator, as shown in

Fig. 13. The measurement campaign was carried out in two phases. In the former, the corpse was acquired as it was, i.e. covered by the oilcloth. In the latter, the 3D measurement was carried out after the removal of the oilcloth and of the ground: the aim was to obtain a complete 3D image of the whole skeleton, shown in Fig.14. Each measurement session took about thirty minutes.

Table 2 shows the parameters of the measurement used in the two sessions.

Focal lengths	FOV (mm)	WD (mm)	Zrange (mm)	Rz (mm)
Wide	780x575	1300	540	0.55
Tele	190x145	800	140	0.15

Table 2: Optical parameters for the acquisition.

In the wide setup, the optical digitizer was used to acquire the corpse, with the exception of the skull, both before and after the removal of the oilcloth. The main difficulties of the acquisitions were represented by the irregularities of the surfaces and by the particular light condition, such as shadow regions and colour variations, due to the sun illumination. In the tele setup the skull was measured. It represented the central element for the legal analysis. Due to the extreme irregularity of its shape and the multiple fractures that it presented, eight views were captured in about twenty minutes. In Fig. 15, the wireframe model of the skull, with the application of the vertices colour information, is presented. The elaboration from task 2 to task 4 was performed in the laboratory, both for the skeleton and the skull.

Figure 12: The corpse in the hollow.

Figure 13: The skull, partially disrupted by the excavator.

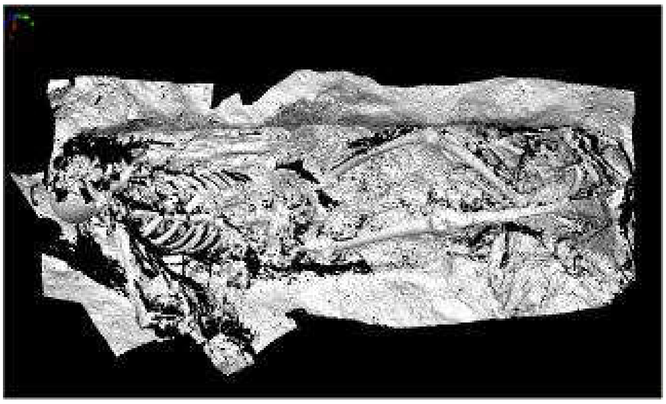

Figure 14: 3D mesh of the whole uncovered skeleton.

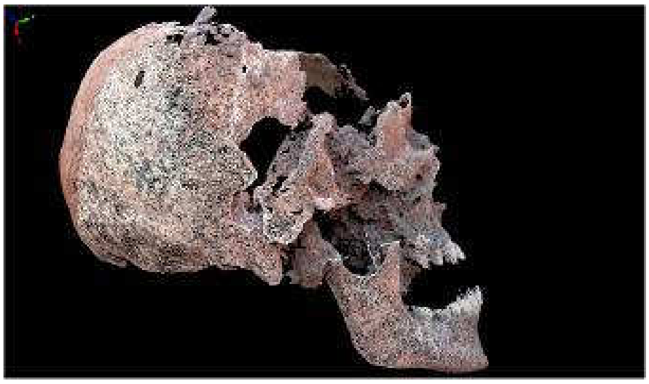

Figure 15: Wireframe model of the skull with the application of vertex colour information.

4.3 *Study case 3: the skull*

The third example of acquisition was aimed to study the skull shown in Fig. 16. It was found broken in pieces and brought to the Institute of Legal Medicine of Milan, where the medical examiners managed to reconstruct it.

Since it was really fragile, the risk of breaking it up again was high: for this reason it was suggested the idea of “fixing” the tridimensional shape of the skull in a digital archive to be able to reproduce it in case of need. To acquire the skull, the configurations reported in Table 3 were used: while the former (medium FOV, average resolution) was suitable to perform global views, the latter (reduced FOV, high resolution) was adopted to acquire details and fractures.

Focal lengths	FOV (mm)	WD (mm)	Zrange (mm)	Rz (mm)
Middle	530x390	850	380	0.25
Tele	140x100	600	200	0.13

Table 3: Optical parameters for the acquisition. See Table 1 caption for explanations of acronyms.

After aligning and merging the acquisitions, we created the polygonal model of the skull, shown in Fig. 17. The purpose of this activity was to produce a prototype of the skull, in order to obtain the replica of the find that can be directly inspected by the medical examiners. We succeeded in this and the resulting prototype, shown in Fig. 18, is currently used by the Institute of Legal Medicine of Milan. The time taken for the acquisition was about half an hour. Task from 2 to 4, were completed in the laboratory.

Figure 16: The reconstructed skull

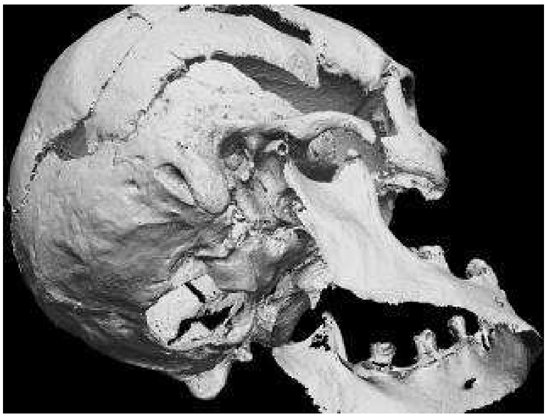

Figure 17: Polygonal model of the reconstructed skull

Figure 18: Prototype of the skull

5 CONCLUSIONS

This paper has briefly presented the possibility and the concrete feasibility of using traditional reverse engineering techniques to document the spatial characteristics of crime scenes, in order to offer an objective and high-resolution data base for the investigations and the analysis of evidence. The described process of acquisition and elaboration lead to appreciable results that are supposed to integrate and enhance those obtainable with traditional techniques. The experts of the field have encouraged the prosecution of the researches and some new experiences of particular applications of RE are going to start, both in the criminal/forensic and the medical/surgical field.

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