Application of three-dimensional optical acquisition to the documentation and the analysis of crime scenes and legal medicine inspection

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Abstract

This paper presents the activities aimed at testing the performance of a 3D optical system, designed for industrial and standard reverse engineering applications, to carry out the contact-less acquisition for crime scene documentation and analysis. In particular, the study focuses on two aspects. The former is the "in-field" measurement and modeling of crime scenes; the latter is the analysis of lesions, organs, bone tissues and skin wounds during legal-medicine inspection.

Several study cases are presented, in order to show the high potential, the flexibility and the effectiveness of the measurement based on the optical three-dimensional approach.

The paper is organized in three different sections. Section 1 briefly overviews the operative contexts and explains the purposes of the work. Section 2 describes the instrumentation and the methodology used to perform the data acquisition and elaboration. Section 3 presents the experimental cases.

Section 1 – Introduction

In the last decades, the use of three-dimensional instrumentation for the contact-less gauging of surfaces has becoming increasingly relevant in many fields. An impressive number of techniques and systems have been originally developed for the fast acquisition and the reverse-engineering of complex shapes: the goal was to capture in short times and at reasonably accuracies (and costs) free-form shapes, in view of their reshaping and prototyping [1]. The concepts and the methodologies underlying these processes have found fruitful exploitation in many applications, starting from the traditional quality control in the industrial and manufacturing production, to the restitution of heritage, to the virtual reality word, and to medicine applications [2-3].

One of the fields where the use of contact-less, accurate, fast acquisition should be of great advantage is represented by crime scene investigation. This activity indeed requires the complete, accurate and objective description of a very complex and intrinsically three-dimensional scenario, which should be documented at minimum invasiveness and time [4].

Traditional techniques, based on the use of contact rulers and on the two-dimensional acquisition of the scenes, do not match all these requirements: hence, in recent times, investigation techniques have moved toward more advanced methods, such as photograph stitching, virtual reality and photogrammetry [5-6]. These methods have partially fulfilled the lacks of the traditional approaches. However, neither they intrinsically produce three-dimensional information (as in the case of stitching) nor they provide full contact-less measurement (as in the case of photogrammetry).

The Laboratory of Optoelectronics has been working for years at the development of three-dimensional digitizers and to their use in full-optical reverse-engineering applications [7-11]. In 2004, a new field of application was started, in the frame of the collaboration with the UACV (Unità Analisi Crimine Violento, meaning Violent Crime Analysis Unit), a special unit of the Italian State Police instituted and run by Dr. Carlo Bui. The main goal was to assess the feasibility of using long-range three-dimensional sensors for the accurate, digital storing of crime scenes [12]. In this research, a commercial, long-range instrument, based on the time of flight technique, was used to acquire very large scenes (i.e., rooms and courtyards), as well as medium details (i.e., the victim) [13]. In addition, a short-range system, developed by the Laboratory, was used to measure human faces, in view of their prototyping. In

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2005, the activity was funded by the Italian Ministry, in the frame of the project entitled "Dalla scena del crimine, alla costruzione di un modello per l'analisi e interpretazione dei dati, al profilo logico-investigativo dell'autore di reato". Since 2005 a lot of work has been carried out. The Konica-Minolta Vivid 910 instrument was used to perform the contactless acquisition of the targets of interest. The activity has been split in two parts: on one side we collaborated with the policemen in both simulated and real crime scenes, on the other side we worked together with legal doctors to provide a full study of body lesions during the autoptical investigation.

The main goals can be summarized as follows:

1: to study the measurement performance of the optical digitizer in critical work conditions, characterized by (i) the presence of a number of different operators, (ii) the short time available for the measurements, (iii) the extremely high variability of the illumination conditions as well as of the surface colours.

2. to develop an efficient methodology for the elaboration of the raw acquired data, in view of (i) their minimal degradation with respect to the original shapes and (ii) their fruitful analysis and manipulation by operators with minimum computer science training.

3. to provide significant study cases to the specialists in order to have their feed-back about (i) the quality of the measurements acquired by using our optical digitizer for the scene documentation and analysis, (ii) the effective usefulness of the information that can be extracted from our 3D data with respect to the typology of information and documentation that is currently used for legal purposes, and (iii) the possibility of documenting crime scenes by using 3D models that represent a unique repository of measurements, easily retrievable from different operators in different times and locations.

In this paper, a number of interesting results are presented. Among the large amount of experiments that we have performed so far, three cases have been selected for their significance. These are (i) the documentation of a real crime scene, (ii) the measurement of parenchyma and bone tissues during the autopsy, and (iii) the study of skin lesions.

Section 2 – Hardware and software for the acquisition

The optical 3D digitizer used for acquisitions is the Konica Minolta Vivid 910 shown in Figure 1 [13]. 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 back from the target surface, and captured at an angled acquisition direction by a CCD camera. The shape of the surface is determined from the deformation induced on the laser stripe by the object shape. The whole area is captured in 2.5 seconds (0.3 seconds in FAST mode). A RGB 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 focal length), MIDDLE (14mm focal length) and TELE (25mm focal length). They increase the range of the measurement parameters and allow the system to easily adapt to the acquisition problem. One of the main advantages of the instrument is that it does not require the calibration prior to the measurement sessions: this characteristic is particularly relevant in the considered application, in which the capability of rapidly varying the measurement setup is often crucial.

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

1. The acquisition of the point clouds. To accomplish the 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 [15].
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.

Section 3 - The cases of study

The first case of study was a real crime scene, i.e. the discovery of a corpse buried sixteen years ago in a wood-land near Milan (Italy). The challenge of this work was represented by the possibility of carrying out our experiments in a real context, characterized by the presence of specialized operators on the scene, by the necessity of following precise protocols of intervention, and by very rigid time constraints. In addition, we had to face with the problems deriving from even strong variations of illumination, due to both the sun light and the shadows.

The second study case concerned the contactless measurement of human tissues. The experimental work was carried out at the 'Laboratorio di Antropologia ed Odontologia Forense' (LABANOF) located at the University of Milan. The experiments were accomplished in the anatomic room, during the daily scheduled autopsies. The purposes of the work were (i) to verify the portability and the efficiency of the optical instrumentation in a very critical environment such as the anatomic room, (ii) to verify the possibility of measuring the surfaces of interest, such as the skin, the wounds, the internal organs, and (iii) to verify the usefulness of such studies for legal medicine diagnoses.

Study case 1: the real crime scene

The corpse was lying in a hollow, 30 cm deep, and was nearly entirely covered by a oilcloth. As shown in Figure 2.a, the only uncovered parts were the skull and portions of the right thighbone and the tibia.

The measurement campaign was carried out in three phases. In the first one, the corpse was acquired as it was, i.e. covered by the oilcloth. In the second one, the 3D measurement was carried out after the removal of the oilcloth and of the loam, as shown in Figure 2.b. In the last one, the objective was to gauge the skull of the victim, shown in Figure 3.

(a)

(b)

Figure 2 – The corpse in the hollow. (a): The corpse before the removal of the oilcloth; (b): The corpse after the removal of the oilcloth

Figure 3 - The skull, partially disrupted by the excavator

In all the phases, the main requirement was to perform the acquisitions at the best completeness, to ‘capture’ the scene before the removal of the corpse, without slowing down the activities of the police officers and of the technicians.

The acquisition of the corpse was performed following a multi-resolution representation of the scene, i.e. adapting the measurement resolution to the dimension, the complexity, and the significance of the measurement targets. The main goal was to obtain digitally-storable, objective representations of the scene and, at the same time, to keep the data files at reasonable dimension, especially in view of their use on non dedicated hardware and by operators without informatics skills.

To this aim, the optical system was configured in the setups shown in Table 1. The Wide setup was used to acquire the whole corpse in the first two phases. Each phase required the storing of fifteen views, to fill the gaps left by the irregularities of the surfaces and by the light conditions, the shadows and the colour variations of the corpse. The Tele setup was used to capture the skull. In this case, eight views were acquired, due to the high discontinuities of the surfaces (note, in Figure 3 the lesions left by the excavator paddle during the researches of the corpse) and to the importance for subsequent analysis of this part (the victim was killed by a projectile shot toward the back side of the skull). The acquisitions required thirty minutes for each phase. This time is comprehensive of the time required to perform a rough alignment of the views, to avoid exclusion of some parts. The subsequent elaboration was performed in the laboratory, both for the skeleton and for the skull.

Geometrical Setup	**Setup 1 Wide Lens (8mm foc. length)**	**Setup 2 Tele Lens (25mm foc. length)**
Parameter	[mm]	[mm]
WD	1300	800
FOV	780x575	190x145
Z Range	540	140
Rz	0,55	0,13
Rx	0,62	0,15
Ry	0,62	0,15
Ua	0,17	0,12

Table 1: Optical parameters for the acquisition. FOV: Field of View; WD: Working Distance; Zrange: Range of measurement in the perpendicular direction with respect to the lens; Rz: Measurement resolution; Rx, Ry: Lateral resolution on X and Y axis; Ua: Measurement uncertainty.

Figure 4 and Figure 5 show the whole point clouds obtained after the registration of the partial views acquired during phases one and two. The quality of the alignment can be easily appreciated looking at the screenshot in Figure 6. Here, the crucial parameter is represented by the standard deviation of the points that belong to overlapping regions in adjacent views. It can be noted that the average value is about 0.5mm: this value is by for the most accurate with respect to the values obtained by using contact rulers.

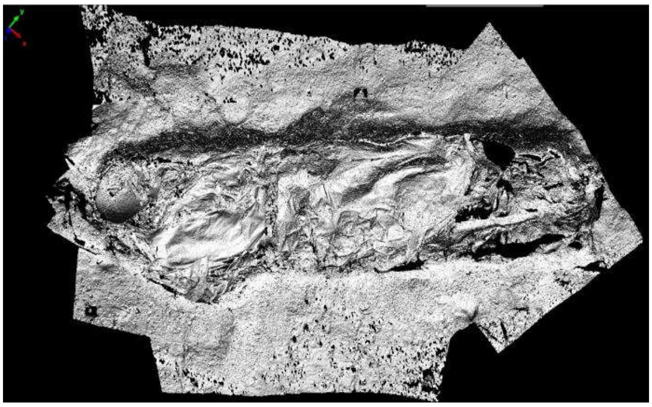


Figure 4 – Three dimensional measurement of the corpse. Point cloud of the corpse before the removal of the oilcloth.

The subsequent elaboration of the original point clouds led to the description of the scene in terms of polygon models (triangle meshes). One of the most relevant and useful characteristic of such topological representations is given by the possibility of extracting suitable metrical data from the models, since each point has a precise position (X,Y,Z) in the 3D space, that univocally identifies it.

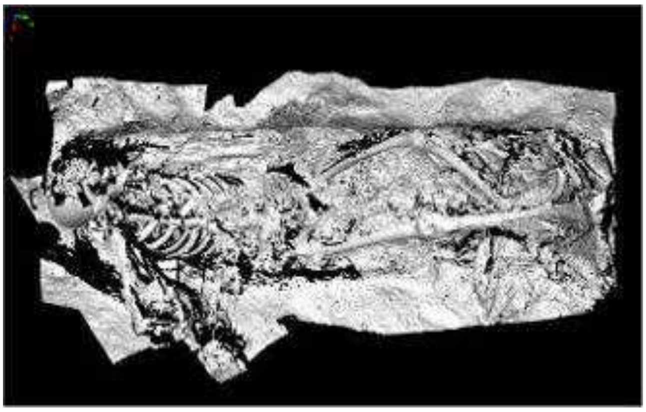
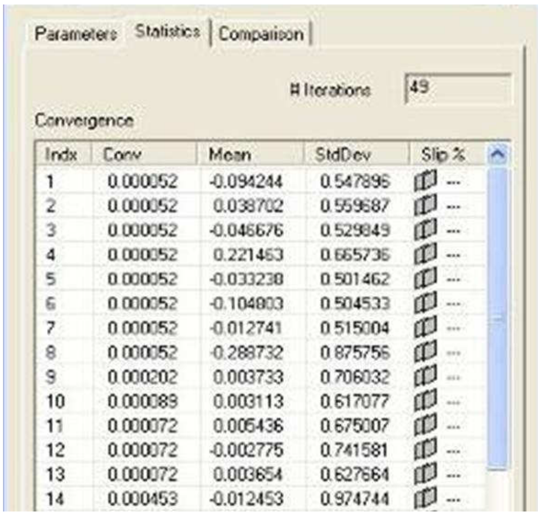


Figure 5 – Three dimensional measurement of the corpse. Point cloud of the corpse after the removal of the oilcloth.



Parameters | Statistics | Comparison

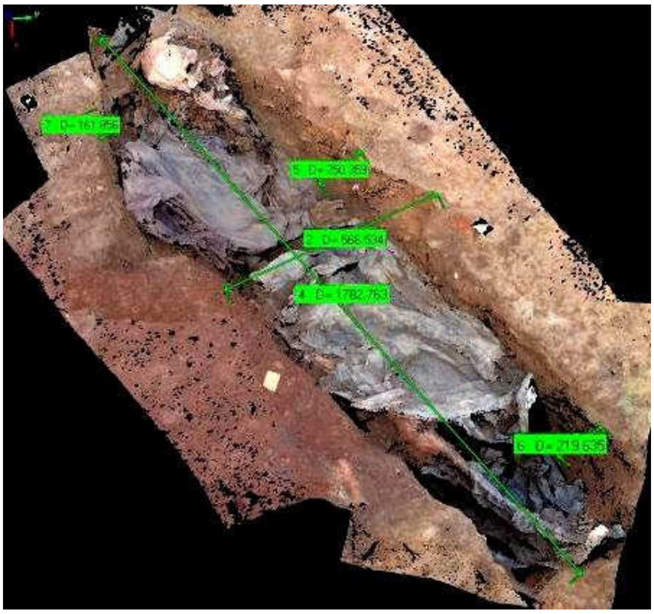
Iterations: 49

Convergence

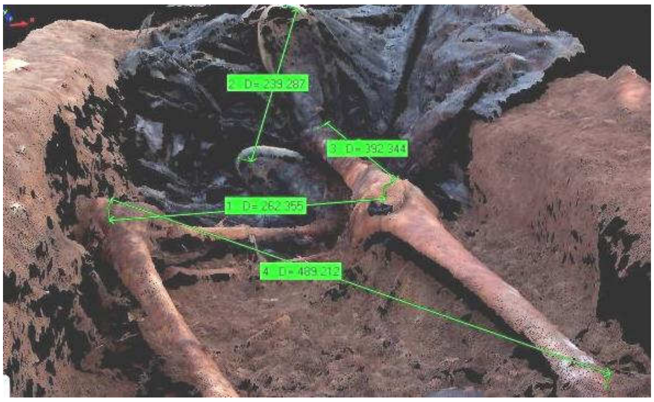
Indx	Conv	Mean	StdDev	Slip %
1	0.000052	-0.094244	0.547896	...
2	0.000052	0.038702	0.559687	...
3	0.000052	-0.046676	0.529849	...
4	0.000052	0.221463	0.665736	...
5	0.000052	-0.033238	0.501462	...
6	0.000052	-0.104803	0.504533	...
7	0.000052	-0.012741	0.515004	...
8	0.000052	-0.288732	0.875756	...
9	0.000202	0.003733	0.706032	...
10	0.000089	0.003113	0.617077	...
11	0.000072	0.005436	0.675007	...
12	0.000072	-0.002775	0.741581	...
13	0.000072	0.003654	0.627664	...
14	0.000453	-0.012453	0.974744	...

Figure 6 – Alignment index for 3D mesh of the covered skeleton

Hence, the operator can extract either point-to-point distances, areas, and sections along selected directions, by using very simple interactive, mouse based procedures. In addition, the availability of the RGB color information as well as the possibility of zooming, rotating, and viewing the mesh along selectable points of observation allows the virtual interaction with the scene, and the observation of even small details that, following the classical methods of documentation are lost after the crime scene removal. An example of these potentialities is presented in Figure 7. These images show the distance measurements that have been performed on the models of the whole corpse, and give an idea of how it is possible to observe the scene at the computer monitor, even after the removal of the corpse.



(a)



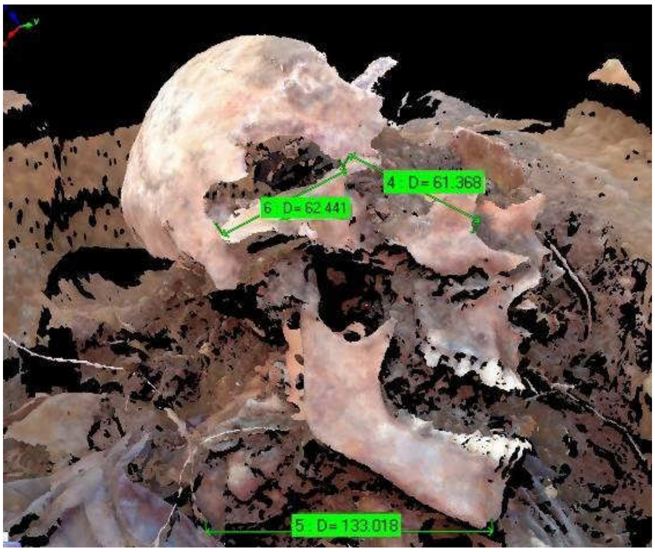
(b)

Figure 7 – Extraction of point-to-point measurements from the triangle mesh. (a): Examples of the measurements performed on the whole corpse; (b): Virtual interaction and measurement of the lower part of the skeleton

The same results have been observed for the modelling and analysis of the skull. Figure 8.a shows the model of the skull (wireframe plus color). This model is very accurate: it has been obtained from a point cloud that showed a mean value for the standard deviation of the alignment below 0,2mm.

Three relevant measurements have been performed on it, and are shown in Figure 8.b. These are (i) the length of the anterior lesion on the skull, including the wide exit hole of the bullet fired against the victim of the murder, (ii) the distance between the edge of the lesion and the nose septum and (iii) the distance between the mandible's extreme and the closest strip of the oilcloth.

(a)



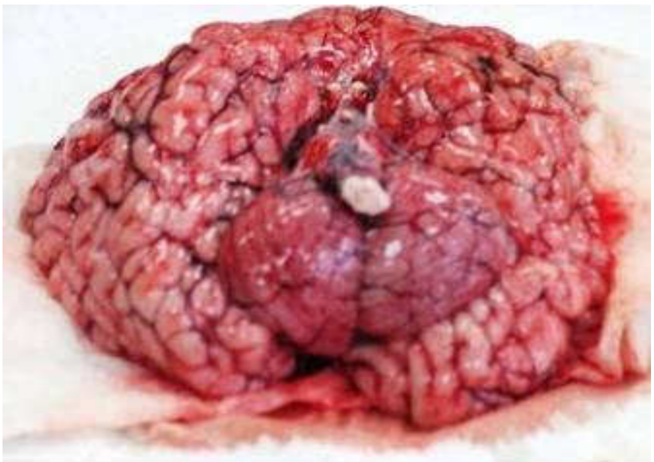
(b)

Figure 8 – Three dimensional mesh of the skull. (a): Wireframe plus color; (b): Example of the extraction of critical measurements before the removal of the corpse.

After the acquisitions and the policemen's routine operations, the legal doctors removed the corpse to perform the laboratory analysis: the original 'physical' posture was lost, while the three-dimensional models still preserve it indefinitely.

Study case 2 – The acquisition of human tissues

The tissues that were acquired are shown in Figure 9. These are (i) the brain just extracted from the cranium during an autopsy in Figure 9.a, (ii) the skin wound due to a car crash in Figure 9.b, and (iii) the bone lesions left by the offender on the portion of the femur (about 20cm long) in Figure 9.c.



(a)

(b)

(c)

Figure 9 – The targets acquired in the anatomic room. (a): The brain; (b): The skin lesion; (c): The bone lesions

The experimentation in the case of the brain was aimed at assessing the feasibility of using the optical system to acquire a surface highly reflective, variable in the colour, and characterized by significative variations of the shape. It is worth noting that, since the brain was extracted from a three-months old baby, it was practically impossible to touch it without deforming its shape. The acquisition was performed at a relatively short distance from the target (about 60cm), in order to acquire all the details and to minimize the alignment errors. Figure 10 shows the point cloud obtained after the registration of 9 views. The triangle mesh created starting from this point cloud allowed us to extract a number of interesting measures. As an example, Figure 11 shows the process of extracting the sections along pre-selected directions, defined by the operator. The profile of this section is plotted in Figure 12. Figure 13 shows the measurement of the area corresponding to the cerebellum zone (i.e. the lower back portion of the brain).

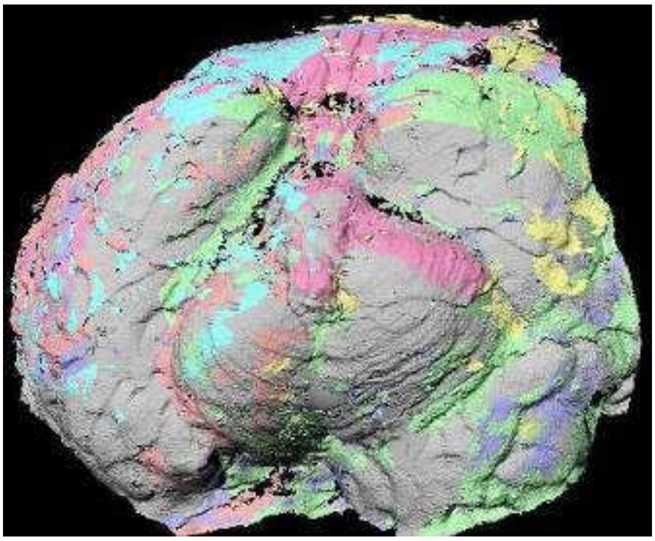


Figure 10 – Result of the multi-view registration.

The aim of the work in the experiment on the face in Figure 9.b was to study the sensitivity of the optical measurements, i.e., to assess if it was possible to gauge the shape, the deepness, and the contour of the skin wounds that were visible on the front head of the victim.

Due to the small dimension of the lesions, the optical system was configured in the Tele setup. Figure 14 shows the wireframe representation of the lesion framed by the blue rectangle in Figure 9.b, while Figure 15 presents the measurements of the depth and of the width of the wound.

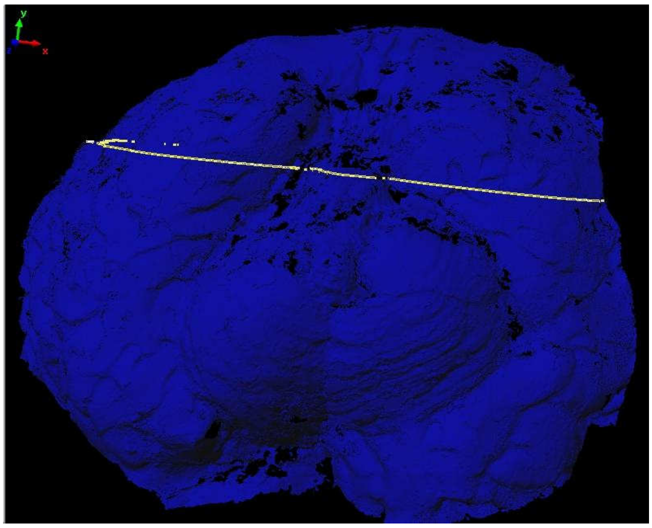


Figure 11 – Section extracted from the model of the brain perpendicular to Y Axis

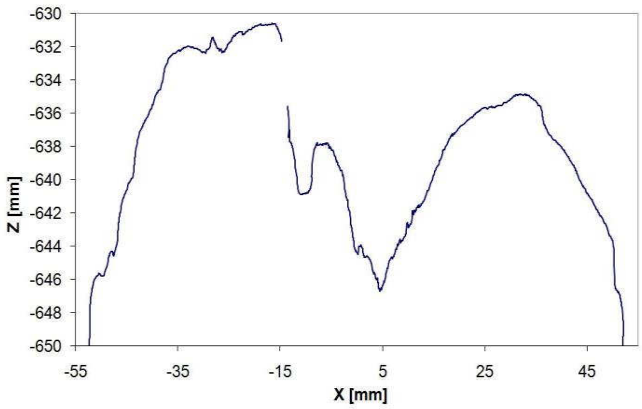


Figure 12 – Section of Figure 11 – 2D representation

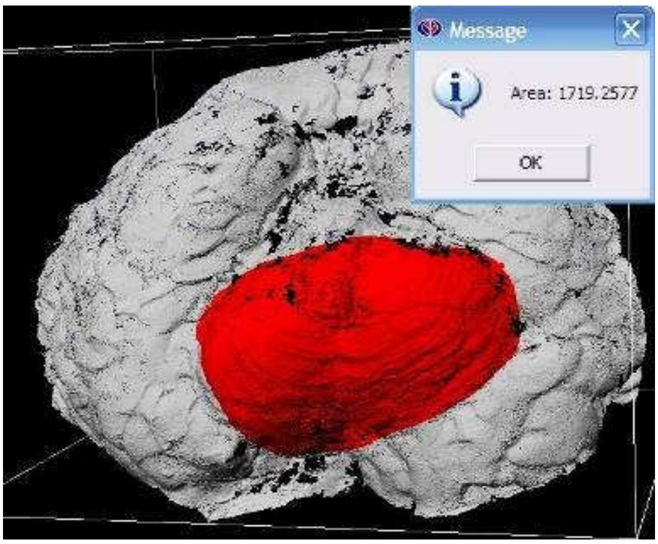


Figure 13 – Measurement of the area of the cerebellum

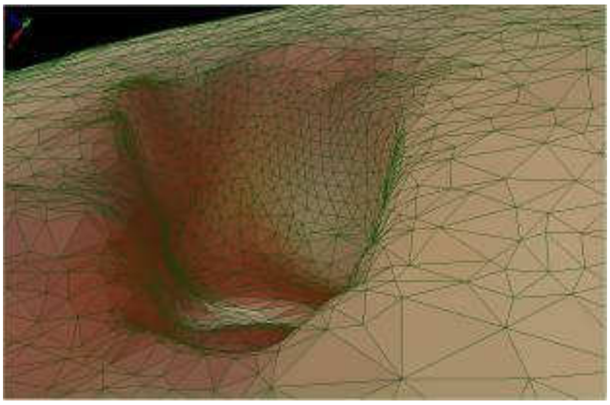


Figure 14 – The high definition, colored “flat+wireframe” view of the wound.

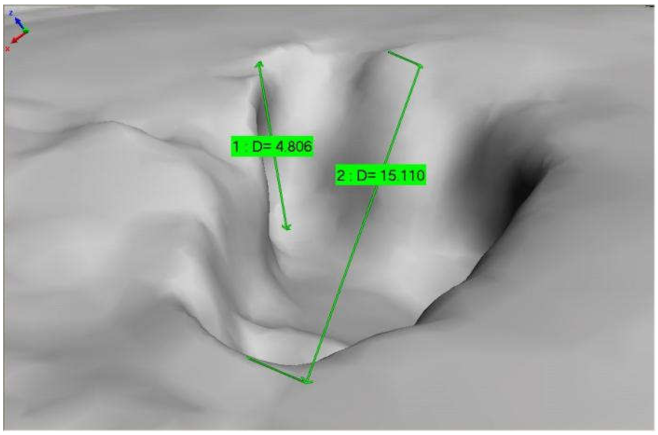


Figure 15 – Measurement of the depth and of the width of the wound

The mesh clearly shows the shape of the lesion, and highlights that even in this case it is possible to extract the dimensional information about its deepness.

The work performed on the portion of thighbone shown in Figure 9.c was aimed at investigating if it was possible to gauge the lesions left on its surface by a cutlass. The bone was measured by using the same setup as before. The tridimensional mesh was created by acquiring and aligning 8 different views. The apparently high number of views was necessary due to the reduced area of the acquisition setup and to the high curvature variation of the surface. On the other hand, the resolution of the measurement is lower than 100μm and results in a very high adherence of the 3D raw data to the original surface. After the alignment of the point clouds the triangle mesh shown in Figure 16 was obtained. The blue rectangles on the picture evidence the areas interested by the lesions. This mesh well highlights the presence of the transversal grooves left by the cutlass. Figure 17 zooms on the largest rectangle: by means of the superposition of a metrical grid, it is useful to perform the ‘on-the-fly’ eye measurement and to obtain the immediate perception of distances and curvature variations of the surface.

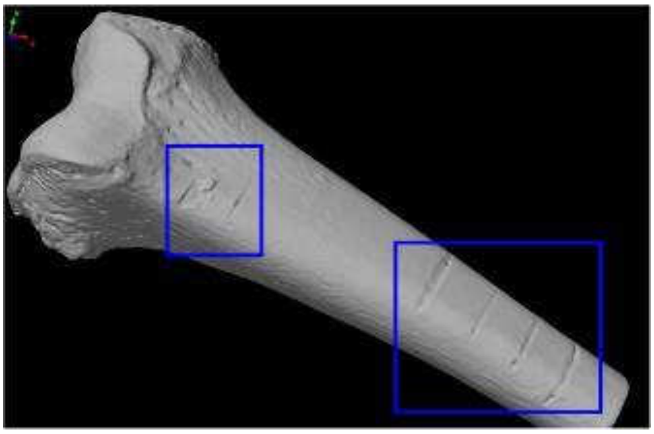


Figure 16 – 3D mesh of the thighbone: the areas interested by the lesions are framed

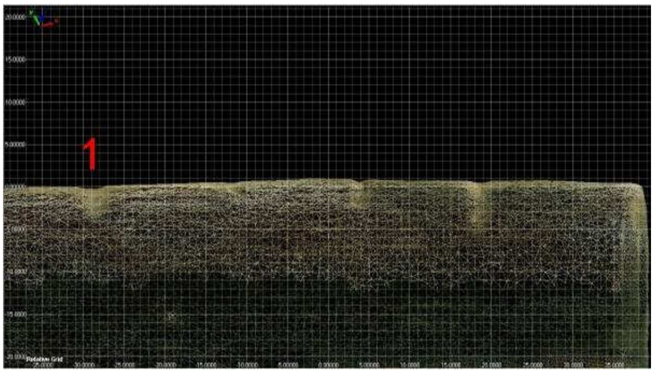


Figure 17 – Zoomed view corresponding with the zone framed by the largest rectangle in Figure 16

The use of the mesh as the information support for the inspection and the measurement operations that are often mandatory during the analysis of the data is well observable in the example shown in Figure 18. Here, the lesion labeled by ‘1’ in Figure 17 is zoomed in order to extract the distances that are useful to make reasonable hypotheses on the type of the cutlass.

Conclusions

In this paper, a brief overview of the experimental work performed to assess the feasibility of applying the reverse-engineering process to the three-dimensional data acquired by using an optical range system during the walk-through of crime scenes and in the legal medicine analysis has been presented.

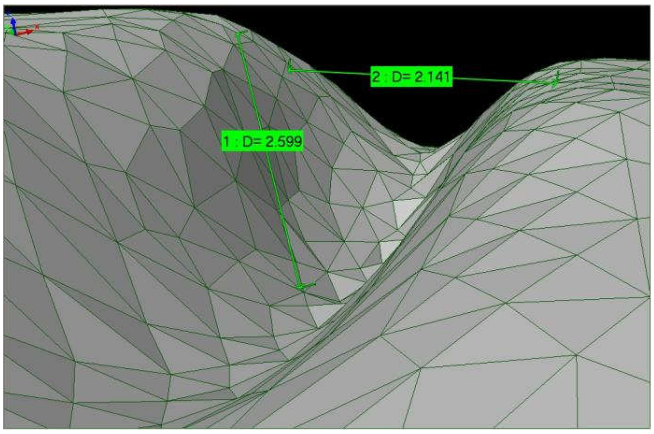


Figure 18 – Close distance view and measurement of lesion labeled by '1'

The experimentation performed so far has evidenced that this methodology does overcome some crucial limitations that are typical of the traditional approaches. Among these we cite the non invasiveness, the completeness and the speed of the data acquisition, that are compatible with the normal work of the investigators.

As far as our experience is concerned, the availability of three-dimensional models allowed us (i) to document the spatial characteristics of crime scenes, in order to offer an objective, and multi-resolution data base for the investigations and the analysis of evidences, and (i) to support the legal doctor analysis during the autoptical exam, by acquiring relevant elements for further analysis and elaborations.

The proposed process can integrate and enhance the results obtainable by using the traditional techniques, in view of getting a more complete and objective representation of the analyzed targets. The experts in the fields we worked with during the experimentations have encouraged the prosecution of the research to fully explore the potentialities of the methodology.

References

[1] F. Blais, "A review of 20 years of range sensors development", *Journal of Electronic Imaging*, N. 13(1), 2004, pp. 231-240.

[2] G. Roth, P. Boulanger, "CAD model building from multiple range images*", Proc.Vision Interface,* N. 98, 1998, pp. 274-281.

[3] P. Boulanger, G. Roth, G. Godin, "Application of 3D active vision to rapid prototype development*", Proc. Intelligent Manufacturing System (IMS), International Conference on Rapid Product Development*, 1994, pp. 147-160.

[4] M.J. Thali, M. Braun, W. Bruschweiler, R. Dirnhofer, "Matching tire tracks on the head using forensic photogrammetry", *Forensic Science International*, N. 113, 2000, pp. 281-287.

[5] http://www.ptgui.com/info/photo_stitching.html

[6] W. Bruschweiler, M. Braun, R. Dirnhofer, "Analysis of patterned injuries and injury-causing instruments with forensic 3D/CAD supported photogrammetry (FPHG): an instruction manual for the documentation process", *Forensic Science International*, N. 132, 2003, pp. 130–138.

[7] G. Sansoni, A. Patrioli, F. Docchio, "OPL-3D: a novel, portable optical digitiser for fast acquisition of free-form surfaces," *Rev. Scient. Instr.*, Vol. 74, N. 4, 2003, pp. 2593-2603.

[8] V. Carbone, M. Carocci, E. Savio, G. Sansoni, L. De Chiffre, "Combination of a vision system and a Coordinate Measuring Machine for the Reverse Engineering of Freeform Surfaces", *Int. J. Adv. Manuf. Tech.*, N. 17, 2001, pp. 263-271.

[9] G. Sansoni, F. Docchio, "In-field performance of an optical digitizer for the reverse engineering of free-form surfaces", *International Journal of Advanced Manufacturing Technologies,* published on-line on 23 September 2004, DOI: 10,1007/s00170-004-2122-7.

[10] G. Sansoni, F. Docchio, "Three-dimensional optical measurements and reverse engineering for automotive applications", *Robotics and Computer-Integrated manufacturing,* Vol. 20, 2004, pp. 359-367.

[11] G. Sansoni, and F. Docchio, *"*3-D optical Measurements in the Field of Cultural heritage: The Case of the Vittoria Alata of Brescia"*, IEEE Trans. Instr. Meas.,* Vol. 54, No. 1, 2005, pp. 359-368.

[12] F. Docchio, D. Rossi, G. Sansoni, "Modellazione del viso umano mediante tecniche di triangolazione attiva e mediante fotogrammetria", *Atti del XXII Congresso Nazionale Associazione "Gruppo di Misure Elettriche ed Elettroniche"*, 2005, pp. 257-258.

[13] F. Docchio, G. Sansoni, M. Tironi, M. Trebeschi, C. Bui, "Sviluppo di procedure di misura per il rilievo ottico tridimensionale di scene del crimine", *Atti del XXIII Congresso Nazionale Associazione "Gruppo di Misure Elettriche ed Elettroniche"*, 2006, pp. 255-256.

[14] http://www.minolta3d.com

[15] http://www.innovmetric.com