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PHOTONIC METHODS APPLIED TO HERITAGE CONSERVATION IN ARGENTINA

María Mercedes MORITA[1,*]; Gabriel Mario BILMES[1,2]

[1] Laboratorio de Ablación limpieza y Restauración con Láser. Centro de Investigaciones Ópticas (CONICET-CIC). Casilla de correo N°3 C.P.1897 Gonnet, Bs.As. Argentina.

[2] Facultad de Ingeniería, Universidad Nacional de La Plata. Calle 1 y 47, La Plata, Buenos Aires, Argentina

Abstract

As part of an ongoing program performed in collaboration with museums and institutions of Argentina, we present results on the application of laser based techniques and 3D imaging methods for material characterization, cleaning and documentation of cultural heritage objects, particularly the collections of public museums located in different regions of the country. In this work, we present results on the application of Laser Induced Breakdown Spectroscopy (LIBS) for material characterization of objects found in the ex-detention, torture and extermination center called Club Atletico (Instituto Espacio Memoria) of Buenos Aires. We also show laser cleaning applications to archaeological objects found in Patagonia and in the city of Buenos Aires. Finally, we present a 3D system developed for recording and documentation of artworks. It is based on digital photogrammetry and uses low cost devices and free software for data processing. This 3D system has measurement tools and the possibility of creating deterioration maps in the virtual model. We present examples of the applications of this 3D system to artworks from argentine museums.

***Keywords**: LIBS; laser cleaning; 3D documentation; digital photogrammetry; Structure from Motion; Photonic techniques in conservation*

Introduction

Since 1999 the Laboratory of Laser Ablation, Cleaning and Restoration (LALRL, in Spanish) at *Centro de Investigaciones Ópticas* (CIOP), in La Plata, Argentina, has developed applications of photonic methods for the conservation of cultural heritage. Particularly, laser cleaning of documents, glass, fabrics, metals, leather and bones of archaeological value [1, 2]; the application of Laser Induced Breakdown Spectroscopy (LIBS) for the characterization of the composition of rescued underwater archaeological objects and other archaeological pieces [3-6]; and image processing techniques to evaluate different cleaning methods of paper and to obtain information of marks in walls [7-8]. In recent years, the LALRL has started a research and development program with museums and institutions of Argentina that involves the application of laser based techniques and 3D imaging for material characterization, cleaning and documentation of their collections [9]. These institutions are the *Instituto Espacio para la Memoria*, that is in charge of the research, diffusion and conservation program of ex-clandestine detention, torture and extermination centers in Buenos Aires; the *Museo del Hombre y su Entorno* (MHE, Santa Cruz, Argentina); the *Área de Museo y Patrimonio de la*

* Corresponding author: mercedesm@ciop.unlp.edu.ar, mercedesmorita@yahoo.com

Facultad de Bellas Artes of the *Universidad Nacional de La Plata*, (MPFBA, La Plata, Argentina) and the *Centro de exhibiciones Palacio* Nacional de las Artes *"Palais the Glace"* (PG, Buenos Aires, Argentina). None of these institutions had previous experience on using photonics methods and 3D imaging for conservation and documentation of their collections.

Clandestine detention centers (CDC) were secret facilities used by the army and security forces to execute the person's disappearance systematic plan, implemented by the civil-military dictatorship that took power in Argentina between 1976 and 1983. There were more than 600 across the country, among the best-known *Escuela de Mecánica de la Armada* (ESMA), *Club Atletico*, *Campo de Mayo*, *Mansion Sere*, *Olimpo* and *La Perla*. In its last stage, the dictatorship attempted to destroy evidences of the existence of these places by literally demolishing the buildings, by removing or painting walls, or by covering marks. But that was not enough to erase all traces of the given use. The importance of conservation of these sites is that CDC are part of the remains and evidence of what happened to people who were victims of state terrorism. The restoration and conservation of the CDC is, on one side, for the purpose of recovering the historical memory as material support of state terrorism, and, on the other one, to preserve them as evidence in court proceedings. It is in this context that a demand has been arisen for the application of photonic techniques for the site survey, architectural restoration tasks, recording and image processing, analysis of the material composition of objects, identification and recording of marks made with pencils or sharp objects and coated with paint, etc.

Regarding documentation of cultural heritage, argentine museums do not have advanced imaging techniques to disseminate their collections or to interact with the public and researchers. The existing computer systems for the administration of collections and dissemination of cultural heritage have incomplete databases, and generally the only method of image acquisition for documentation is the two-dimensional photography. Moreover, there is a demand by museums and national institutions to use image processing methods for the documentation of cultural heritage objects. The interest of these institutions lies in digitizing a part of their collections. By agreements with these institutions, LALRL is developing some projects with the aim of providing them with a system for acquisition and processing 3D images. On one hand, there is the designing of a kit based on digital photogrammetry and Structure from Motion, with free software and low-cost instrumentation, for free usage by museums and institutions across the country. This system would be easy to use and enables a complete high-detailed image for documentation and recording of dimensions in objects, and a wide dissemination of the museum's collections. LALRL would provide also the training of human resources of the museums in these technologies, and also the access to laboratory options, such as 3D structured light scanning, laser scanning and interferometric techniques for those cases in which high resolution images or particular studies are required.

In this work, we present results on the application of Laser Induced Breakdown Spectroscopy (LIBS) for material characterization of objects found in the ex-detention, torture and extermination center called Club Atlético (of the *Instituto Espacio Memoria*) in Buenos Aires. We show also laser cleaning applications to archaeological objects found in Patagonia and in the city of Buenos Aires, and finally we present 3D imaging methods applied to the documentation of collections of three argentine museums that are part of the program in course.

Materials and Methods

LIBS System used for characterization of the composition of objects

During the excavation and reconstruction of the clandestine detention center *Club Atlético*, different objects were found. Some of them were complete and in good conditions, but for the most part, the objects were incomplete and mostly covered by corrosion. In the latter situations, it was necessary to identify the main composition of the substrate beforehand and use the information for the identification, conservation and restoration of these objects. To do this, Laser Induced Breakdown Spectroscopy (LIBS) was used for the determination of the composition of eight pieces of metal objects found in the excavations of the site.

LIBS requires no sample preparation, can eventually be applied *in situ*, and it has significant advantages over conventional techniques in the analysis of unique objects of cultural heritage value [10]. LIBS is based on spectroscopic analysis of the radiation emitted by plasma, generated during sample ablation with a laser pulse, and performs best when it is used to determine the qualitative composition of an object. Measurements are fast and easy to be performed. The samples were irradiated in air at normal room conditions with an infrared Nd:YAG pulsed laser (1064nm), with duration pulses of 7ns, 100mJ energy. The laser was focused perpendicularly to the surface of the sample with an F = 15cm lens, allowing it to achieve fluences up to 7J/cm^2. A fused silica optical fiber was used to collect the light emitted by the plasma. Detection and analysis were made by using an Ocean Optics HR2000+ spectrometer (resolution 1.5nm) with a laboratory made delay generator. To avoid Bremsstrahlung emission a time delay of 500ns was used. LIBS spectra were recorded at 300-800nm wavelength range. Figure 1 shows the setup used for LIBS.

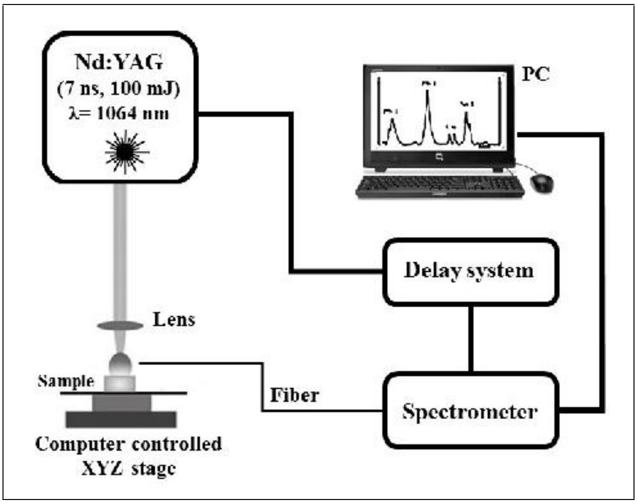

Fig. 1. Setup used for Laser Induced Breakdown Spectroscopy (LIBS).

Laser cleaning of archaeological objects

Laser cleaning of copper and porcelain archaeological objects was performed combined with traditional cleaning methods to eliminate active corrosion, surface dirt and marks made for their classification. A commercial Q-switched Nd:YAG, 10ns pulse laser, at 1064nm was used, the same that was used for LIBS analysis as mentioned in the previous section. The repetition frequency, as appropriate, was varied from a single pulse to 10Hz. The laser was focused by means of a lens and, to prevent damage, the fluences of the laser beam were controlled below 1.5J/cm^2 to work in all cases below the respective threshold values of the substrate. The samples were mounted on a computer controlled triaxial system and the cleaning procedure was controlled by optical inspection. In all the cases the criterion used was the minimal intervention, leaving visible the natural patina.

As part of a more complete study [6], a set of four copper plates belonging to the MHE found in a multiple burial of hunter-gatherers in Patagonia, Argentina, were restored by using laser cleaning. The burial contained remains of an adult male and two children, one partially burned, and they were dated at 730±60 years BP. The plates were found over the body of one of the children. The cleaning of the objects was first performed by a mechanical method, using scalpels, brush and rubber. After this, the chemical cleaning was implemented: hyssop with distilled water and baths of sodium carbonate buffer. Laser cleaning was the technique to complement the traditional cleaning. Lastly, a protection layer (PLIOLITE®AC80) was put over the plates.

Two porcelain toy doll heads belonging to the *Centro de Arqueología Urbana* (CAU) of the city of Buenos were also cleaned by laser. These objects were part of a collection found in excavations of urban archaeology in one of the oldest houses in the city of Buenos Aires. The dirt type was soil and oxide stains. Traditional cleaning methods were previously applied: dry cleaning first, and then water with neutral detergent was applied. Care was taken during the laser cleaning because the laser could remove part of the decorative enamel painting from the piece. The frequency rate was $8cm^2$/min at 10Hz.

Digital photogrammetry with Structure from Motion for 3D documentation

A 3D system for documentation of artworks based on digital photogrammetry with Structure from Motion was developed. The system has measurement tools and the possibility of creating deterioration maps in the 3D model. Low cost devices and free software were employed for 3D scene reconstruction. Generally, for the detailed record of small objects in the millimeter and sub-millimeter scale conservators and archaeologists often rely more on laser and structured light scanning techniques, even though for these purposes the use of close range digital photogrammetry has been reported in the literature [11-13]. Nevertheless, the recent development of advanced image processing techniques opens new possibilities for CRDP for recording objects in a simpler way, with the quality and resolution of scanning techniques. While there are previous works that recognize the possibilities of CRDP for certain applications [14] there has been little systematic study comparing its advantages over other 3D techniques. Mainly in terms of the most appropriate software, requirements, quality, cost and resolution [15-22]. As it was previously recognized, to adopt these techniques for accurate measurement purposes, clear accuracy statements, benchmarking and evaluations must be carried out [23].

Digital Photogrammetry with Structure from Motion [24] and free software was applied to sculptures and archaeological objects from three different museums: Naum Knop's "Figura reclinada" and Aurelio Macchi's "Figura, both from the PG; five gypsum sculptures, from the MPFBA; and two of the archaeological copper plates, from the MHE.

In traditional photogrammetry, in order to determine the 3D location of points within a scene, it is necessary to know the position of the cameras or the 3D location of a series of control points. Identification of control points manually, triangulation (for scene geometry) and resection (for camera position) are the three parts involved in the process. Otherwise, Structure from Motion (SFM) requires neither of these things to be known prior to scene reconstruction. In our 3D system, the application of SFM combined with a properly acquisition method and image processing techniques was carried out in the following way: The first step was taking pictures of the object, with high degree of overlapping and from a wide range of positions. To acquire the images, we used a NIKON D300, with focal length 35mm and a sensor size of 23.6x15.8 mm. Images were well focused and sharp, and the resolution was of 14MP. We kept the focal length fixed. The number of images was varied according to the complexity of the object: between 40 and 180 pictures were taken for sculptures of metric sizes and simple geometries (Table 1). The overlap of images was at least 70%, and each image was taken from different perspective. The next step was processing the images with a Structure from Motion software. VisualSFM was used. The Scaled-Invariant Feature Transform (SIFT) algorithm [25], present in VisualSFM in the form of SiftGPU [26, 27], was used to carry out the feature matching of all the images. SIFT identifies features in each image that are constant to the scaling, rotation and partially invariant to changes in illumination conditions and camera viewpoints. Key points are automatically identified over all scales and locations in each image, followed by the creation of a feature descriptor. Corresponding features must be visible in a minimum of three photographs; however, obtaining many images for SFM input as possible is highly recommended, as this optimizes the ultimate number of matches [28, 29]. The number of key points determines the resolution of the digital photogrammetric product that depends on the following factors: the resolution of the camera used the size of the object to be photographed, the number of photographs taken and their geometric arrangement.

After this feature detection, the reconstruction of the 3D scene is performed with an iterative process called Bundle Adjustment [30]. Bundle Adjustment is the refining of a visual reconstruction that involves the estimation of the viewing parameters (camera position and/or calibration) compatible with the optimal 3D structure. The result is a 3D point cloud. This is a low-density or sparse point cloud. A higher density point cloud can be obtained by applying the Clustering View for Multi-view Stereo (CMVS) and Patch-based Multi-view Stereo (PMVS2) algorithms [31, 32].

The final step in the construction of the 3D model is the surface reconstruction and texturing. The point cloud is converted to a mesh of polygons or triangles. This can be done using surface reconstruction algorithms. We used MeshLab [33], an open source software, to accomplish this task, and to perform mesh processing and editing. The meshes were generated with the Poisson Reconstruction filter [34] and, then, texture was applied from the photos using texturing filters [35, 36]. But this process was rather complex and required a lot of time because in many objects the point cloud had sparse areas and few soft color vertices corresponding to the object's reflections during the image acquisition, in addition to small areas without resolution. So, to optimize the result, instead of using CMVS, the output of VisualSFM (sparse point cloud) also was input in the CMP-MVS software [37]. This software lets face the difficult surfaces as transparent and highly reflective. It improved the reconstruction of the surfaces which were not sampled densely enough by the 3D point cloud. MeshLab was also used for alignment in the cases when we obtained different meshes, by applying the point based method and the ICP algorithm.

Camera positions derived from SFM do not have the scale provided by control points. In order to obtain a 3D model at a real scale to take measurements virtually, we used a ruler placed in an appropriate part of the sculptures.

Table 1 summarized the artworks that were 3D reconstructed and documented with the system presented in this paper.

Table 1. Name of the artworks and archaeological objects documented with the 3D photogrammetric system. The institution to which it belongs, the materials from which they are composed and the number of photographs taken are also displayed

Name of the artwork	Institution	Materials	Number of photographs
"Figura reclinada"	*Palais de Glace*	Marble	86
"Figura"	*Palais de Glace*	Bronze	89
Bas-relief "Segador"	*Área de Museo y Patrimonio de la Facultad de Bellas Artes*	Gypsum	144
Bas-relief "El invierno"	*Área de Museo y Patrimonio de la Facultad de Bellas Artes*	Gypsum	177
Bas-relief "La vendimia"	*Área de Museo y Patrimonio de la Facultad de Bellas Artes*	Gypsum	161
Chapiter with fantastic animals	*Área de Museo y Patrimonio de la Facultad de Bellas Artes*	Gypsum	68
Chapiter with figure	*Área de Museo y Patrimonio de la Facultad de Bellas Artes*	Gypsum	147
Copper plate 969	*Museo del Hombre y su Entorno*	Copper	46
Copper plate 970	*Museo del Hombre y su Entorno*	Copper	40

Results and Discussions

LIBS was used for the characterization of elemental composition of objects from the site *Club Atlético*. Figures 2 and 3 show two examples of the analysis performed by LIBS: the spectrum of what was possibly a bottle top (Fig. 2) and the spectrum of an unidentified metal plate with holes (Fig. 3). Table 2 summarizes the analyzed objects and their elemental composition.

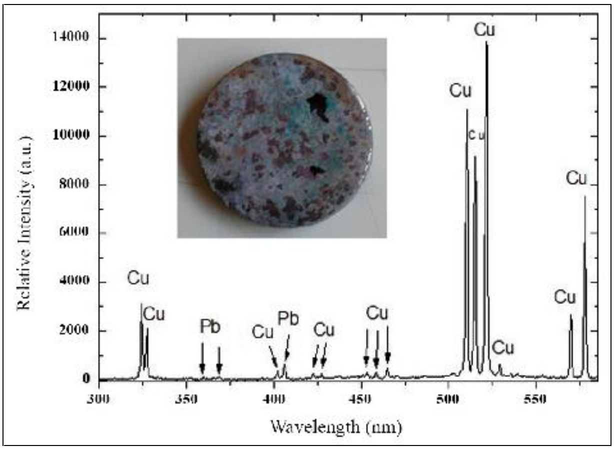

Fig. 2. LIBS Spectrum of what was possibly a bottle top

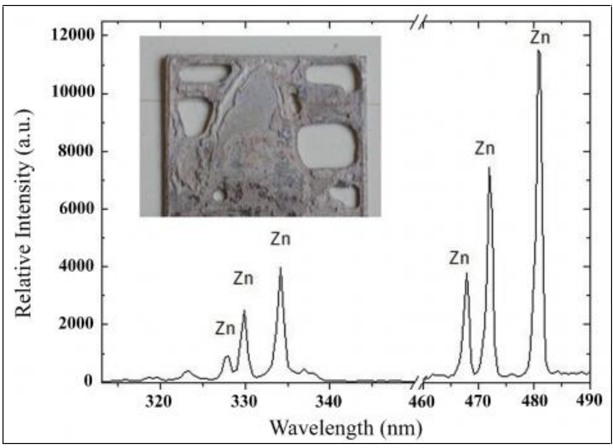

Fig. 3. LIBS Spectrum of an unidentified metal plate with holes

Table 2. Objects found in *Club Atlético* and their composition determined by LIBS

Object	Composition
Part of a spoon	Cu, Zn, Pb
Buckle	Cu, Fe
Chain links	Cu, Zn, Pb
Piece of a bell	Fe
Unidentified piece of metal	Fe
Unidentified metal plate with holes	Zn
Part of a razor handle	Cu, Pb, Zn
Bottle top	Cu, Pb

Laser cleaning was performed in four archeological copper plates from the MHE. With mechanical cleaning, it was possible to eliminate a large part of the active corrosion, clay remains and concretions of the copper plates. Distilled water removed residual salts, and the baths of sodium carbonate buffer eliminated most of the active corrosion too. Laser cleaning was efficient in removing a part of corrosion and painting from the signs without damaging the substrate, especially for fragile parts. Figure 4 shows partial results during laser cleaning procedure. Figure 4-a shows one of the plates before restoration, in which it can be seen the active corrosion and marks made with white paint for its classification (Fig. 4-c). In figures 4-b and 4-d both the white paint marks and the active corrosion were eliminated with laser cleaning. The decoration in the edges with perforations was more visible after the restoration.

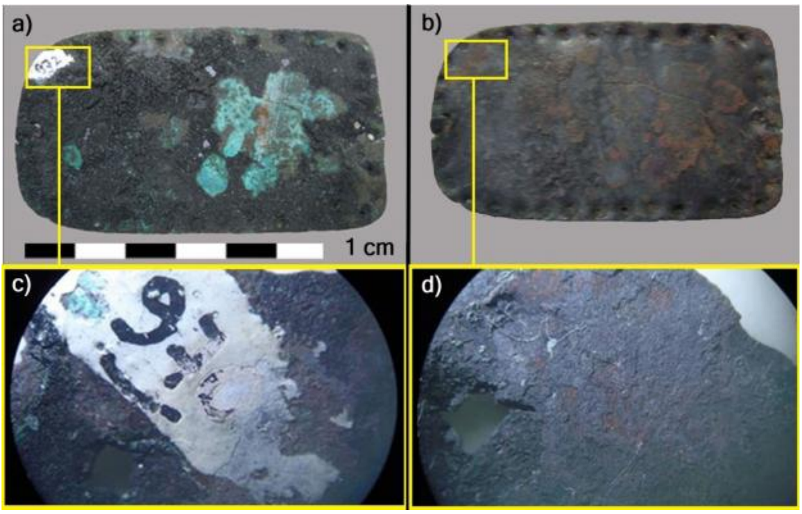

Fig. 4. Laser cleaning of an archaeological copper plate belonging to a multiple burial of hunter-gatherers found in Patagonia, Argentina. a, c) Original state with active corrosion and marks made with white paint for its classification. b, d) After laser cleaning

The traditional cleaning methods previously applied to the porcelain dolls were not effective, because most part of the soil was embedded. On the other hand, when laser cleaning was applied, the laser interacted only with the dirt, without damaging the substrate. Practically no residues were generated as most of the dirt evaporated and the vapors were collected by aspiration. Figure 5 shows one of the toy heads before and after laser cleaning.

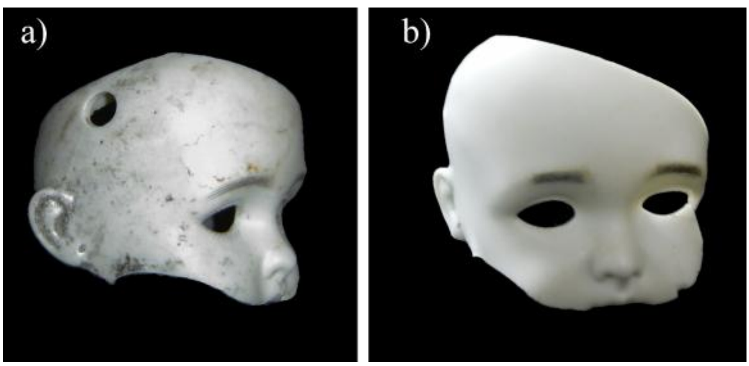

Fig. 5. Porcelain doll head. a) Before laser cleaning. b) After laser cleaning

Regarding the 3D reconstruction with SFM, it was possible to achieve good quality 3D models of the different sculptures. Good quality means that the meshes were not deformed and had good resolution. In all cases the resolution of the 3D model was determined by comparing the distance between two points of the 3D model and a measurement in the real object, performed with a caliper of 0.02mm resolution, according to the different areas. For the metric size sculptures, the resolution was ~ 1 mm and for the plates it was ~ 0.3mm. Figure 6, on the left, shows a sparse point cloud from Naum Knop's "Figura reclinada". Therefore, the data were exported from VisualSFM to be input to the CMP-MVS. The result was a textured mesh. Besides, it was necessary to remove the "artefacts" that did not belong to the model. Figure 6, on the right, shows the final 3D model after using CMP-MVS.

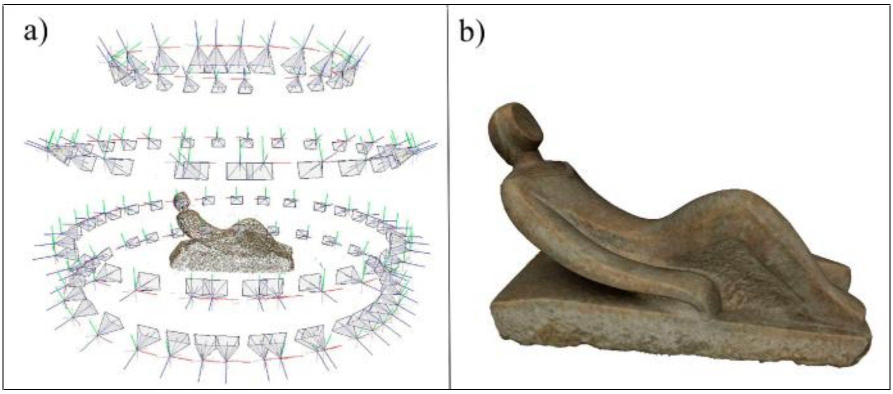

Fig. 6. Photogrammetry using VisualSFM. a) Point cloud (inside) and camera positions (outside) of a marble sculpture called "Figura reclinada" by Naum Knop, PG collection. b) Final 3D model after using CMP-MVS

Figure 7 shows the surface reconstruction procedure of a gypsum relief called "Segador" from the MCFBA collection. The same method was used.

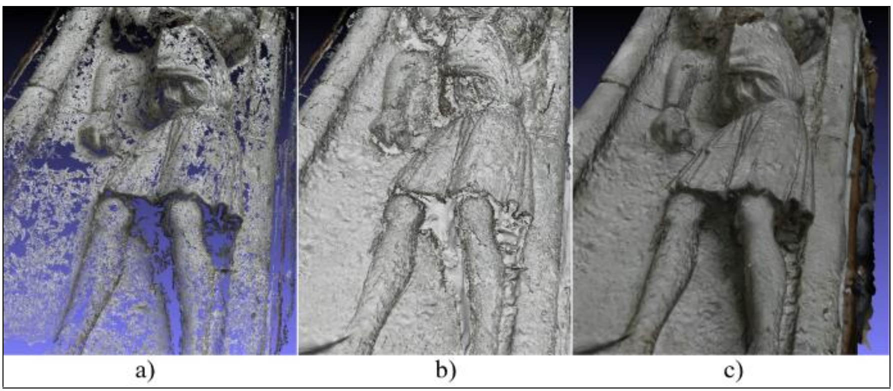

Fig. 7. Steps from the surface reconstruction of a gypsum relief called "Segador", MCFBA collection. a) Incomplete dense point cloud obtained from CMVS. b) Poisson filter applied to the point cloud. Observe areas with poor resolution, as the area between the character's legs and under his dress. c) Textured mesh achieved with CMP-MVS. Observe the enhancement of resolution in those areas

One advantage of this 3D system is that it is possible to use meshes obtained in different acquisition moments. Figure 8 is such an example. In this case, the bronze sculpture "Figura", from the PG, was reconstructed by the alignment of two meshes in a single one, using MeshLab.

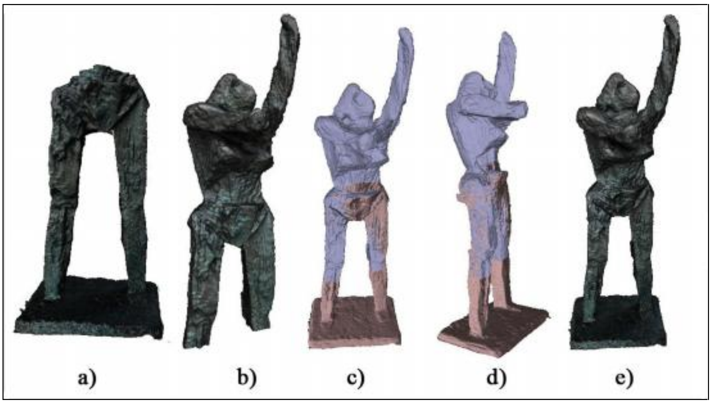

Fig. 8. Alignment of two meshes of the bronze sculpture "Figura" by Aurelio Macchi from PG, obtained in different acquisition moments. a) First mesh. b) Second mesh. c, d) Fused mesh obtained by the alignment tool of MeshLab. e) Final 3D image by applying surface reconstruction filters and texture from photos to the mesh

Conclusions

We applied the photonic techniques such as LIBS, laser cleaning, and 3D digital photogrammetry for material characterization, cleaning and documentation of the collections of the public museums and heritage institutions in Argentina.

LIBS characterization of several pieces belonging to *Club Atlético* (*Instituto Espacio Memoria*) of Buenos Aires was performed. The spectra of the pieces are now part of the documentation of the *Instituto Espacio para la Memoria*, and they are available to be used in future interventions and conservation treatments. In our experience, LIBS continues to demonstrate that is one of the best fast qualitative analysis methods to determine the main composition of unique pieces of heritage value. Based on this experience we are developing a portable LIBS system that can be used *in situ* as part of a service that LALRL provides to public museums. The system has the main components already described, but uses a passive Q-switched Nd:YAG laser (1064nm) with small dimensions, developed by the *Grupo de Tecnología Láser* (GTL) from CICATA IPN, in collaboration with the Bralax laser Lab company, both from Altamira, México.

We performed laser cleaning of archaeological objects combined with traditional cleaning methods, to eliminate active corrosion, surface dirt, and marks made from their classification. In this type of application, laser cleaning demonstrates that is a solution in the restoration of unique pieces that are fragile or have natural patinas to preserve.

We have also performed a low-cost 3D system based on photogrammetry that can be used on archaeological objects and artwork documentation that is free and easy to use by museum staff and conservators. The 3D system is based on the open source software VisualSFM, using SIFT and Bundle Adjustment, complemented with CMP-MVS to optimize the construction of dense point clouds. This 3D system is already used by museums and heritage institutions of Argentina, as part of a project to digitize their collections hierarchically, and enhance their value.

It is noteworthy that the 3D records presented in this paper represent some of the first experiences of using this type of technology in Argentina for documentation of archaeological pieces and art objects of argentine museum collections and public heritage institutions.

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