JPhys Photonics

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To cite this article before publication: Diego Ivan Quintero Balbas *et al* 2024 *J. Phys. Photonics* in press https://doi.org/10.1088/2515-7647/ad41ab

IOP Publishing Journal Title
Journal **XX** (XXXX) XXXXXX https://doi.org/XXXX/XXXX

3D scanning of daguerreotypes

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Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

Daguerreotypes are historical photographic images made on mirror-like metallic plates. These are heritage objects whose shape cannot be measured with invasive techniques, like contact probes, but the high reflectivity of their surfaces makes the use of non-invasive, 3D-measuring optical techniques challenging. Moreover, the dark areas resulting from their degradation produce a very high contrast, which add extra difficulties to their measurement. In the last few years, several strategies have been developed to overcome the limitations of optical techniques when measuring reflective metallic surfaces. Many of these solutions are not applicable to the study of cultural heritage artifacts, as they are invasive. We attempted the use of conoscopic holography in a 3D-scanning system using a double-exposure strategy. This is a promising option for 3D measuring of daguerreotypes, as we experimentally demonstrated in this work. We present the results obtained from the analyses of two 19th-century daguerreotypes with different superficial conditions. The double-exposure allowed us to obtain high-quality data from the entire object surface. This enabled the measurement of micro-scale details related to the manufacturing process and/or to the corrosion deposits. The proposed methodology can be exploited to monitor the overall health of highly reflective metallic objects but also the outcomes of some conservation treatments, such as cleaning.

Keywords: daguerreotypes; surface metrology; conoscopic holography; 3D optical profilometry; 3D modeling; laser microprofilometry; photography

1. Introduction

Daguerreotypes were the first commercially available photographic images, formed by Ag-Hg (and in some cases also Au) nanoparticles (NPs) on mirror-like Ag-Cu plates. Daguerreotype images can either appear negative or positive. Their nano-scale structure, fragility, and superficial optical properties [1] make the measurement of their surface micro-topography challenging for contactless optical techniques. This limits the recording of the micro-features related to the technology of production, degradation, and evaluation of conservation treatments.

The optical properties of a daguerreotype surface depend on the shape, distribution, and density of the metallic particles. Previous research demonstrated that the optical response of the plate surface results from the scattering of light by the metallic NPs, which are estimated to have sizes in the range of 300-800 nm [2]. Their size is inversely proportional to their density: lower-density areas have bigger NPs [1]. This produces the characteristic negative-positive appearance of daguerreotypes: the plate's polished surface has a mirrorlike reflection, and the diffusion produced by the small metallic NPs can become negligible with respect to this reflection depending on the illumination/observation angles [3], thus changing the angle(s) can change the appearance of the image.

Additionally, optical properties of daguerreotype plates change with degradation. Barger et al. [4] estimated that a silver sulfide layer of 500-1000 Å is enough to modify the properties of the surface, producing nuances that range from a bluish-red to a black color [5]. Additionally, the formation of silver chloride, another common degradation product in daguerreotypes, induces morphological changes in the metallic NPs [6]. The abovementioned phenomena impact on the appearance of these artworks, their conservation state and hamper their fruition.

In this respect, the characterization of daguerreotypes, conducted mainly at the nano- and micro-scale, exploiting various microscopic methods (e.g., confocal microscopy, SEM-EDS, AFM, and synchrotron-based techniques [7–9]) aims at understanding of diverse corrosion phenomena and at supporting restorer during the conservation procedure. The main efforts, conducted at a macro and mesoscale, have focused exclusively on digitization of the photographic image and to its digital recovery when corrosion of the surface is extensive [10,11]. The specular reflection of the mirror-like surface is one of the main challenges when digitizing daguerreotypes. This issue has been overcome by using high-dynamic-range imaging or modified scanner systems [10]. Another obstacle to the correct measure of the micro-topography can be the dark regions, generally associated with tarnishing (i.e., silver sulfide, silver oxide) - the most common corrosion phenomenon in daguerreotype plates.

3D investigations of the plates' shape are not frequently reported in the scientific literature and most are limited to specific regions of interest (ROI) of small dimensions (in the order of millimeters). For instance, confocal microscopy was applied to monitor the effect of cleaning methods on the micro-topography of the plate surface [7]. Similar attempts have been made with optical coherence tomography (OCT) to register the effect of laser induced breakdown spectroscopy (LIBS) measurements on the surface and to correlate the data with the stratigraphic distribution of the elements detected [12], or to study corrosion deposits, such as copper formates [13].

3D metrology of specular metallic surfaces represents a challenge for most systems available today. Contact techniques (i.e., stylus-based testers) [14] are not applicable to the study of daguerreotypes due to the fragility of the surface that is susceptible to scratches. On the other hand, the 3D contactless surface measurement methods, broadly categorized into (1) triangulation, (2) time-of-flight and (3) wave interference (holography, conoscopy), might be chosen according to the metrological requirements (e.g. accuracy, object size, etc.). The latter, also known as the interferometry-based surface metrology, is widely exploited for its high measurement accuracy. The contactless optical systems to retrieve the 3D surface of an object (i.e. laser scanning, structured light projection, interference-based methods (holography and conoscopy), and time-of-flight methods) [15] may be affected by unwanted optical phenomena that occur in the presence of specular surfaces (e.g., reflection or interreflections when transparent or semi-transparent layers are present) or by dark areas, which most of the optical systems struggle to register adequately [16]. To overcome this inconvenience, several strategies have been adopted in the industrial field, for example, by applying matte coatings to reduce specular reflections, using multiple lights, point sources, or screens, employing polarizing filters during measurement, or modifying the set-up geometry by changing the instrument angle during scanning [15–17].

Some of these strategies are not applicable to the study of cultural heritage objects (e.g., applying coatings) and can introduce errors in the measurement, reduce the capacity of registering dark areas (i.e., using filters), or increase the time required for measuring and data processing (i.e., measuring with many diverse setup geometries) [18].

In the heritage science field, the most similar application for the study of small metallic objects is the analyses of coins. Because of their small size and of their highly reflective surface, their 3D digitization is a challenge [19]. Morris et al. [20] developed a workflow for an effective 3D digitization of small coins by photogrammetry equipped with macro-lenses, circumventing the specular reflection by changing the camera angle without modifying the lighting direction. This approach allowed for the creation of 3D models including the coin edges. Schirripa Spagnolo et al. [21] proposed a low-cost fringe projection profilometry, based on a digital micro-mirror device to generate flexible structured-light patterns, for the surface acquisition of the coins. Fusion of data, obtained with more than one acquisition system at diverse scales and spatial resolutions, proves to be effective with coins, yet, this might not solve the problem of specular reflections or dark areas' measurement [22].

Alternatively, to avoid specular reflection interference in optical metrology, a multiple exposure system for structured light instrumentation was proposed by Zhang but this method is practicable only without ambient light [17]. Another approach, based on high dynamic range phase-shifting fringe projection, exploits fringe image fusion algorithm to avoid saturation and under-illumination phenomenon by choosing the pixels in the raw fringes. The latter, acquired with different camera exposure time and the illumination, with the highest modulation intensity are used to create synthetic fringes. This methodology increases the measurement automation and represents a suitable alternative to overcome non-invasively the problem of specular reflection in measurement even at ambient conditions [19]. The method is under development regarding several parameters of the digital fringe projector such as the fresh rate, range and resolution of the light intensity.

Another method to retrieve the 3D surface - the Conoprobe distance-meter - uses conoscopic holography to extract the target distance with micrometric precision. To provide distance information, the laser power needs to be adjusted according to the target reflectance. If the conoscopic hologram is either underexposed or saturated, the device cannot measure properly. The probe was originally introduced for industrial use, and it performs at its best on reflective, uniformly colored surfaces. When applied to the analysis of cultural heritage objects, abrupt changes in the target reflectance are common, and the measurements are more difficult, as the laser power needs to be matched to the average reflectance of the area under investigation. Holes in the Z map due to saturation/underexposure of pixels are quite common when the target reflectance is far from being uniform. Conoscopic holography has been successfully applied to measure metal surfaces and evaluate the results of different cleaning methodologies. The signal-to-noise (SNR) ratio, provided by the instrument driver as a percentage value, was used to evaluate the quality of the output of the probe [23,24]. The authors [23] developed a routine to optimize the performance of the conoscopic holography probe for the multi-material characterization, demonstrated on a Russian icon. By using the SNR value as threshold, a stack of acquisitions with different laser settings is combined into a single optimized surface map.

The challenge with measuring daguerreotypes is that they cannot be considered as uniform targets. They have a strongly reflective surface produced by the mirror-like polishing but also diffusive areas due to the Ag nanoparticles, and finally high-reflective and/or very dark areas where corrosion spots are located. Moreover, the small metallic particle size represents a disadvantage for the conoscopic measurements. Speckle noise is produced when the roughness of the surface is at the scale of the wavelength of the light employed in the system (in our case λ=649 nm) [25]. A phenomenon that is also produced by specular surfaces [26]. To solve this issue, multiple recordings are common optical strategies to reduce noise [25].

To overcome problems of saturation/under illumination due to the material inhomogeneity and its other intrinsic properties we developed a double-exposure acquisition workflow for a customized conoscopic holography, as described in this paper, allowing the acquisition at two different laser power values. Being the acquisitions mapped onto the same reference system by the X-Y scanning stages, the dense point cloud describing the 3D shape of the measured surface, is already hardware registered. This paper shows the capability of a calibrated conoscopic holography instrument coupled with a tailored multiple exposure scanning system to obtain high-quality 3D maps of the entire surface of daguerreotype plates, even from specular and dark regions.

2. Materials and methods

2.1 Daguerreotypes analyzed

Two 19th-century daguerreotypes (Table 1) were employed as targets for this study. The objects belong to the Chiesa-Gosio private collection (Brescia, Italy) kindly made available for the purpose of this research project. Both daguerreotypes present degradation materials (i.e., formates, cyanide compound, and Ag sulfides as examined by Raman spectroscopy) deposited over the surface and other micro-scale features (i.e., hallmarks) of particular interest for the present study.

The daguerreotypes were fixed to the optical table (Fig. 1b) using a tailored sample holder with micrometric movements to align the entire object surface with the plane where the laser diode is focused.

2.2 Experimental apparatus

3D acquisition of daguerreotypes is achieved through an in-house built scanning micro-profilometer. Its core element is a commercial conoscopic holography distance meter (Conopoint 10, Optimet, Israel), equipped with a diode laser (peak emission wavelength λ=649 nm) and a 25-mm focusing lens (Figure 1), mounted on two high-precision motorized linear stages (M-531, Physik Instrumente). The laser power at the sample surface can be adjusted in the range of 1.9 μW to 655 μW. With the help of control software, its value is set to the optimum value according to the measurement requirements, as detailed in a following section. The X, Y linear stages of the device allow for a maximum scanning area of 30 × 30 cm^2. Depth (Z) and in-plane (X-Y) resolutions are about 3 μm and 40 μm, respectively. The Z-measurement range is about 2.0 mm, when operating with a 25 mm lens, as specified in Table 2. The measurement X,Y step size was set 20 μm, but the actual lateral resolution is given by the laser spot size in the focus region, which in this case is 40 × 40 μm^2.

The scanning micro-profilometer is powered by an in-house designed (C# coded) software application, that we named Cono2022. This software controls and sets the power laser at the sample surface, controls and synchronizes the Conopoint probe data acquisition with the motion of the scanning stages. The software allows the real-time 2D and 3D visualization of the acquired data.

The output is a dense point cloud, describing the 3D shape of the measured surface, regularly sampled in X and Y. The Z values can be represented into a 2D map. The sampling steps in X and Y are software selectable: square or rectangular pixels can be used, as small as 10×10 μm^2. On the Z map, image processing can be performed either for noise reduction (e.g., X-Y binning) or for enhancing the visibility of micrometric details of the surface, such as different color rendering techniques, or flattening Z through best plane fitting. For example, the back (verso) of daguerreotype 534, was binned on 2x2 pixels. Despite the reduced image resolution, this allowed a 50% reduction of the Z noise.

Some ROIs selected from the daguerreotype maps were further processed to enhance the micrometric features. We fitted the reference plane of the selected areas with a second- or third-degree polynomial plane and then subtracted it from the dataset. The degree of polynomial fitting was chosen based on the features to be highlighted in the plots, considering that higher degrees can mask small topographic features. For comparison, the same areas were examined under a Leica M205C stereomicroscope with a camera Leica DFC 295 at 0.78× and 1.8× according to the areas investigated. White balance over a white surface was performed before capturing the images processed with LAS v4.6 software.

2.3 Single-exposure scanning

The micro-profilometer scans the object surface by one column at a time. The fast axis is the vertical one (Y), running at the fixed maximum speed of the stage (i.e., 50 mm/sec). The acquisition of the single pixels within a column of data is paced by a clock signal, generated by dividing the stage encoder output signal with a programmable divisor, to give the desired pixel resolutions in Y. When a column of data has been acquired, the X stage is moved of the sampling distance towards the right, and a new column scan is acquired. In the normal single-exposure-scanning mode, the X is advanced after each column is acquired, thus generating an acquisition trajectory that is different for odd and even columns of data. Odd columns, starting from the first, are acquired from bottom to top. Even columns are acquired from top to bottom (traditional snake scan). The perfect alignment of the acquisition positions during forward and backward scanning is secured by a fine calibration of the instrument. The starting position of the column acquisition is finely tuned to make all the Z positions (pixels in the map) coincide in the Y direction with the Z position of the previous column. This is enabled by both the precision/repeatability of the Y translation stage and by the possibility of finely tuning the delay of the column trigger, generated by the programmable divisor.

2.4 Double-exposure strategy and implementation

When the double-exposure mode is activated, the system scans each column twice. This is obtained by advancing the X stage only after the Y is scanned forward and backward (traditional raster scan). The laser power is changed before the same column of data is scanned again. In this way all the column pixels are acquired twice with two different exposures, and they remain perfectly aligned, as the data registration is guaranteed by the hardware calibration described before. When selecting the double-exposure scanning mode, the user is called to set two levels of power, corresponding to two different exposures. In the first scan of the column, going from bottom to top, all the available data points at that laser power are acquired. When scanning again the same column, top to bottom, a different laser power is used to try to complete the acquisition of all the data which were not correctly exposed in the first scan. If the user selected a low laser power for the first scan, all the high-reflectivity areas are acquired first, and the second scan try to fill all the "holes" left by underexposed (in this case) points. The decision to expose first for dark or for white areas is left to the user, and it depends on the target. A fast preview measurement, implemented in the software, helps the user to decide the best exposures to be set.

The acquisition software allows to control the measurement advancement in real time (included the hole-filling) and the estimated duration of the scan. The real-time 2D high-resolution map of the object is shown (using false color scales) as it is progressively acquired by the system.

After the scan is acquired, the application permits to move the Conopoint to precise pixel positions, that the user can select on the map, to inspect the local data quality. This is remarkably useful in case of points which, even after a double exposure, remain not acquired. The user may then reselect new exposure conditions to try to obtain a better acquisition (i.e., less holes in the map).

It is to be noted that, with such implementation, triple and quadruple exposure schemes are possible, even if time consuming, in cases where the target is too contrasted even for double exposure acquisition.

We explored the range of laser power of the probe on different types of materials for achieving the correct registration of conoscopy hologram (i.e., non-under-exposed hologram). As expected, the minimum laser power strongly depends on the surface finish of the material, on its diffusion properties and on its color. On white paper the minimum power to obtain a valid distance is about 11 μW, and the maximum power before saturation is about 49 μW, a range rather small, being contained in a laser power variation smaller than 5 times. This is partly due to laser diffusion inside the target. Indeed, on a glossy white paint on plastic substrate, where the diffusion is almost negligible, the minimum laser power is about 2 μW (close to the minimum power selectable) and the maximum about 0.06 mW. Thus, on this kind of target the dynamic range of laser power is about 30× (the maximum usable power is 30 times the minimum). It follows that the dynamic range, then, varies with the target material and it is generally included in a range of 10×. Materials showing bulk diffusion of the laser light have smaller ranges, while less diffusing materials have the higher ones. We measured the minimum usable power on some reference materials as: 6.4 μW on white canvas; 6.9 μW on white (99% reflecting) Spectralon® reference; 8.6 μW on white cardboard and up to 28.0 μW on matte iron.

3. Results and discussion

3.1 Single-exposure scanning

To test the performance of the system in different scenarios, we measured recto and verso of two daguerreotypes (Table 1, Figures 2a and 4a), with dissimilar superficial characteristics. For the first daguerreotype, the 3D maps (in a 2D false colormap formats) of recto and verso (Figures 2b and 2c) show the surface data of the entire plate. The layer of white corrosion products distributed over the surface reduces the specular reflection, hence, it was possible to obtain high-quality data from the micro-topography and the general form of the plate with a single exposure with laser power set at 0.46 mW and acquisition step of 20 μm. We have further examined a ROI corresponding to a hallmark, useful for the identification of the daguerreotype producer, located in the upper right corner (white rectangle in Figure 2b). Figure 2d shows results of such ROI as a false color image and as a 3D plot in Figure 2f zooming on letters "H" and "B". Figure 2e reports a microphotograph of the hallmark for comparison.

Profile sections (X, Z) extracted from the micro-topography data, along the white dashed lines in Figure 2d, are plotted in Figure 2g (i.e., H from the hallmark and PS from the plate surface, respectively). The results show the curvature of the plate in the edges, associated with the polishing process during manufacturing. The edge curvature is also evident in Figures 2b and 2c. Moreover, it was possible to quantify the size of the hallmark relief imprinted by the manufacturer, depth being in the range of 9 to 31 μm. Such data can be helpful for the comparison and identification of the producers and the possible forgeries. Today they are particularly useful for dating daguerreotype plates [25].

3.2 Double-exposure scanning

A different situation was faced in the analysis of the daguerreotype 534 (Figures 4a and 5a). The plate is in a better condition and maintains its typical mirror-like reflection, however it exhibits several areas with significant deposits of corrosion products. The specular reflection of the surface in conjunction with intrinsically contrasting white and very dark areas — the latter also associated with the tarnish of the silver — hamper the correct registration of the micro-features with a conventional 3D scanning employing a single exposure for the whole surface.

The proposed working methodology begins with optimizing the in-plane focus position of the plate surface with respect to the probe, using the micrometric adjustments of the sample holder platform (Figure 1b). Being the dynamic range of the probe/lens configuration only 2 mm long, this step is important to maintain the best possible data collection conditions. The second step is to verify the optimal laser power settings (power 1 and power 2). This is performed by measuring the complete plate in the fast preview mode (X, Y step sizes of 500 μm) at different laser powers. This coarse preview takes each about 10 min. Based on the fast preview, the response of the incorrectly measured pixels is analysed again by moving the probe to their exact location. There, the second laser power (power 2) is set to obtain the best data considering the fringe shape and intensity (and not the SNR percentage proposed by the producer, as that was found to be unreliable). This test is run on several bad pixels to obtain the optimal average conditions for the power 2. The preview maps can be acquired as many times as necessary based on the complexity of the measured object.

Figure 3 shows an example of three preview maps obtained at different laser powers (i.e., power 1=0.17 mW, power 2=0.46 mW, and power 3=0.65 mW). The lower laser power (power 1) allowed the correct measurement of almost all the pixels, except for the very dark areas (dark red pixels in Figure 3a). On the other hand, when the laser power is raised, most of the darker areas were measured correctly but the white areas saturated the detector (central part of Figure 3c corresponding to the bonnet of the portrayed lady). Moreover, during these tests, the SNR percentage given by the probe control SW was higher than 75% in all the points, showing the difficulty of estimating the data quality by considering this parameter alone. Several fringe patterns were recorded and are shown in Figure 3 (second and third rows).

The results obtained from pixel labelled 1 show that the pattern is disturbed by the low-level signal produced by the absorption of the laser in the dark areas. In an ideal scenario (pixel 2 in Fig. 3a third row), the two channels of the signal graph appear as two perfect sine waves out of phase by 180°. On the other hand, the sensor output signal in pixel 2 (Fig. 3 middle column) is affected by possible multiple reflections or split laser spot (i.e., multiple distances measured simultaneously) as suggested by the shape of the fringe pattern. The results indicate that a simple variation of the laser power is not enough to solve the measurement problems in this case since even at high laser powers, the fringe pattern has a low intensity.

However, by measuring at two different laser powers (1 and 2) it was possible to achieve a map that measures the height of almost the entire surface of the daguerreotype. Based on the preview results, we selected 0.17 mW and 0.65 mW laser powers and performed a double exposure measure with a step size of 20 μm (total measure time ~4 hours, double the single exposure time). Compared to the single exposure measurement, the resulting map showed a significant improvement. A small number of pixels (<1% of the entire map) were incorrectly measured, resulting in holes in the map. The number of holes was further reduced by applying a 2×2 binning, which did not result in any data loss, since an oversampling was performed. Figure 4b shows the entire map of the daguerreotype plate.

A detailed inspection of the map obtained shows the possibility of estimating the height of features at a microscopic level. Particularly, Figure 4d reports the results from a selected ROI shown in Figure 4c. The area is affected by the formation of copper formates and cyanides, also due to the previous conservation treatments. The 3D data enable the numeric quantification of the heights of the formed corrosion crystals (in the range of 2-16 μm) and the characterization of their shape and spatial distribution. The selected ROI (red square in Figure 4a and false color map in Figure 4d, after best plane fitting subtraction) reports the height of the corrosion deposition (Figure 4e). The fitted model is shown in Figure 4f. The application of a polynomial second degree was the best solution ($R^2 = 0.9973$, RMSE = 0.4458) for the form removal, since it avoids eliminating some components from the corrosion deposits and enhances the morphological details of the topographic features. The so-obtained information has a high potential for documenting degradation products and qualitative monitoring the conservation treatments.

Further details that can be measured with this dataset are some of the superficial scratches produced by abrasion, showing the utility of this technique to monitor the effect of cleaning procedures on the plate's surface.

The double exposure strategy was also employed for scanning the verso of daguerreotype 534 (Figure 5a), which presents complex superficial features, such as dark areas of the copper plate, copper corrosion deposit, residues of white paper attached, and black stains of previous conservation treatments. The double-exposure (laser powers set at 0.06 mW and 0.65 mW) mode revealed the most effective to avoid the detector saturation when measuring the white paper remains (visible in Figure 5a) and to measure the dark regions. No post-processing was required for this dataset, apart from the best plane fitting and subtraction.

Figure 5a shows the visible photograph and the 2D map of the height values of the surface of the verso of daguerreotype 534. Green copper corrosion products and black stains are distributed through the surface, their shape suggests they were produced by a previous cleaning procedure performed employing chemicals that induced further degradation. In addition, there are residues of paper probably from the housing systems today lost.

The conoscopic measurements successfully recorded the micrometric features of all these elements as it is observed in Figures 5c and 5e. The form subtraction for the ROI selected in this case was performed using a 3-degree polynomial (R^2=0.9986, RMSE=2.718).

Conclusion

The optical properties of daguerreotype surfaces, characterized by specular reflection and diffusion by nanometric particles, represent a challenge for the 3D measurement with contactless optical techniques. The developed acquisition system presented here provides an effective methodology for registering the superficial microscopic features of the entire objects.

The methodology presented in this research is relatively simple to implement since it is based on repeated conoscopic acquisitions with different exposure intensities. In its simplicity, however, it allows overcoming the typical problems encountered in 3D reconstruction of a daguerreotype related to the presence areas with specular reflection as well as the co-presence of very dark and very light areas. The results point to several scenarios in which the conoscopic holography proves valuable in providing quantitative data regarding the daguerreotype surfaces (e.g., characterization of the hallmarks, presence of corrosion products). It can be applied to other artifacts with similar superficial characteristics.

The so-obtained data may be exploited for different purposes. The high-resolution 3D models can be used to produce the 3D copies to increase the accessibility and fruition of the cultural objects, also by the visually impaired citizens. The 3D model can be employed to generate the digital twin for the connection of other data. Moreover, the data can be used during the conservation interventions, for example to select the most suitable cleaning procedure and to monitor its progress and outcome.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

The authors are very grateful to Gabriele Chiesa and Paolo Gosio (Chiesa-Gosio collection) for access to the daguerreotypes studied and the authorization for using the images presented in this work.

This research is part of the Diagnostica Non invaSiva e conservazione di daghErrotipi e altri materiali fotografici (DIAGNOSE) project co-funded by Tuscany Region, POR FSC 2014–2020-Axis Employment GiovaniSì (Grant No. CUP B53D21008070008), Museo Galileo, El.En. group, and the National Institute of Optics from the National Council of Research (CNR-INO), in collaboration with the Opificio delle Pietre Dure (OPD) and support from the Fondazione Alinari per la Fotografia.

The conoscopic probe was acquired through SHINE project funding (Strengthening the Italian Nodes of E-RIHS, Avviso 424/2018 dell'Azione II.1 PON R&I 2014–2020, DD n. 461 del 14-03-2019, PIR01_00016, CUP B27E19000030007). V.R. was supported by "PNIR - Programma Nazionale Infrastrutture di Ricerca" (Avviso D.D. n 2595 del 24-12-19), Rafforzamento del capitale umano delle Infrastrutture di Ricerca, CIR01_00016, CUP: B82F20000810001.

D.Q.B. is supported by Next Generation EU – Humanities and Heritage Italian Open Science Cloud (H2IOSC) project (CUP B63C22000730005).

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References

[1] Schlather A E, Gieri P, Robison M, Centeno S A and Manjavacas A 2019 Nineteenth-century nanotechnology: The plasmonic properties of daguerreotypes *Proceedings of the National Academy of Sciences of the United States of America* **116** 13791–8

[2] Ravines P, Li L and McElroy R 2016 An Electron Microscopy Study of the Image
Making Process of the Daguerreotype, the 19th Century's First Commercially Viable Photographic Process *Journal of Imaging Science and Technology* **60** 030504-1-030504–10

[3] Beeson S and Mayer J w. 2008 3 Daguerreotypes: Light Captured *Patterns of Light. Chasing the Spectrum from Aristotle to LEDs* (New York: Springer) pp 25–32

[4] Barger M S, Messier R and White W B 1984 Nondestructive Assessment of Daguerreotype Image Quality by Diffuse Reflectance Spectroscopy *Studies in Conservation* **29** 84

[5] Stark A, Filice F, Noël J J, Martin R R, Sham T-K, Finfrock Y Z and Heald S M 2021 Retrieving Tarnished Daguerreotype Content Using X-ray Fluorescence Imaging—Recent Observations on the Effect of Chemical and Electrochemical Cleaning Methods *Heritage* **4** 1605–15

[6] Centeno S A, Schulte F, Kennedy N W and Schrott A G 2011 The formation of chlorine-induced alterations in daguerreotype image particles: a high resolution SEM-EDS study *Appl. Phys. A* **105** 55–63

[7] Ravines P, Wiegandt R and Wichern C M 2008 Surface characterisation of daguerreotypes with the optical metrological technique of confocal microscopy *Surface Engineering* **24** 138–46

[8] Ravines P and Nazarenko A Y 2019 Characterizing the Image Forming Particles of Modern Ungilded Daguerreotypes Using XRD and SEM *Microsc Microanal* **25** 1037–51

[9] Kozachuk M S, Avilés M O, Martin R R, Potts B, Sham T-K and Lagugné-Labarthet F 2018 Imaging the Surface of a Hand-Colored 19th Century Daguerreotype *Appl Spectrosc* **72** 1215–24

[10] Ravines P, Baum K G, Cox N A, Welch S and Helguera M 2014 Multimodality imaging of daguerreotypes and development of a registration program for image evaluation *Journal of the American Institute for Conservation* **53** 19–32

[11] Berger Haladová Z, Bohdal R, Černeková Z, Štancelová P, Ferko A, Blaško Križanová J, Hojstričová J and Baráthová K 2023 Finding the Best Lighting Mode for Daguerreotype, Ambrotype, and Tintype Photographs and Their Deterioration on the Cruse Scanner Based on Selected Methods *Sensors* **23** 2303

[12] Papazoglou D G, Papadakis V and Anglos D 2004 In situ interferometric depth and topography monitoring in LIBS elemental profiling of multi-layer structures *J. Anal. At. Spectrom.* **19** 483

[13] Quintero Balbas D, Cattaneo B, Cagnini A, Belluzzo P, Rossi S, Fontana R and Striova J 2023 The Degradation of Daguerreotypes and the Relationship with Their Multi-Material Structure: A Multimodal Investigation *Sensors* **23** 4341

[14] Townsend A, Senin N, Blunt L, Leach R K and Taylor J S 2016 Surface texture metrology for metal additive manufacturing: a review *Precision Engineering* **46** 34–47

[15] Marrugo A G, Feng G, Zhang S 2020 State-of-the-art active optical techniques for three-dimensional surface metrology: a review [invited] *Journal of the Optical Society of America A* **37** B60–B77

[16] Palousek D, Omasta M, Koutny D, Bednar J, Koutecky T and Dokoupil F 2015 Effect of matte coating on 3D optical measurement accuracy *Optical Materials* **40** 1–9

[17] Zhang S and Yau S-T 2009 High dynamic range scanning technique *Opt. Eng* **48** 033604

[18] Chen F, Song M and Brown G M 2000 Overview of three-dimensional shape measurement using optical methods *Opt. Eng* **39** 10

[19] Jiang H, Zhao H and Li X 2012 High dynamic range fringe acquisition: A novel 3-D scanning technique for high-reflective surfaces *Optics and Lasers in Engineering* **50** 1484–93

[20] Morris G, Emmitt J and Armstrong J 2022 Depth and Dimension: Exploring the Problems and Potential of Photogrammetric Models for Ancient Coins *Journal of Computer Applications in Archaeology* **5** 112–22

[21] Schirripa Spagnolo G, Cozzella L and Leccese F 2021 Fringe projection profilometry for recovering 2.5D shape of ancient coins *ACTA IMEKO* **10** 142

[22] Leach R, Sims-Waterhouse D, Medeossi F, Savio E, Carmignato S and Su R 2018 Fusion of photogrammetry and coherence scanning interferometry data for all-optical coordinate measurement *CIRP Annals* **67** 599–602

[23] Daffara C, Gaburro N, Marchioro G, Romeo A, Basilissi G, Cagnini A and Galeotti M 2017 Surface micro-profilometry for the assessment of the effects of traditional and innovative cleaning treatments of silver *Proceedings of the International Conference LACONA XI* Lasers in the Conservation of Artworks XI (Nicolaus Copernicus University Press) pp 127–40

[24] Daffara C, Mazzocato S and Marchioro G 2022

Multiscale roughness analysis by microprofilometry based on conoscopic holography: a new tool for treatment monitoring in highly reflective metal artworks *Eur. Phys. J. Plus* **137** 430

[25] Restrepo J, Correa-Rojas N and Herrera-Ramirez J 2020 Speckle Noise Reduction in Digital Holography Using a DMD and Multi-Hologram Resampling *Applied Sciences* **10** 8277

[26] Álvarez I, Enguita J, Frade M, Marina J and Ojea G 2009 On-Line Metrology with Conoscopic Holography: Beyond Triangulation *Sensors* **9** 7021–37

[27] Chiesa G and Gosio P 2020 *Daguerreotype hallmarks* (Brescia, Italy: Gabriele Chiesa & Paolo Gosio)

Table 1. General information of the daguerreotypes analyzed in the present work.

Code	Subject	Size (mm)	Surface condition	Notes [25]
519mini	Portrait of Mina and Anna Bergamo	50 × 63	White haze distributed over the surface. Plate deformed due to manufacturing process.	Hallmark: Henry Beaud et C.ie. France. Plate production: 1850-1580 ca.
534	Portrait of a lady with a bonnet	80 × 70	Specular surface with localized corrosion (formates and cyanide compounds) deposits.	Hallmark: E. White Maker, N. Y. Plate production 1844-1851

Table 2. Specifications for the probe-25 mm lens set-up as measured.

Measurement range [mm]	Standoff distance[mm]	Accuracy [μm]	Laser spot [μm]	Dynamic reproducibility [μm]
2	14	3	40	0.4

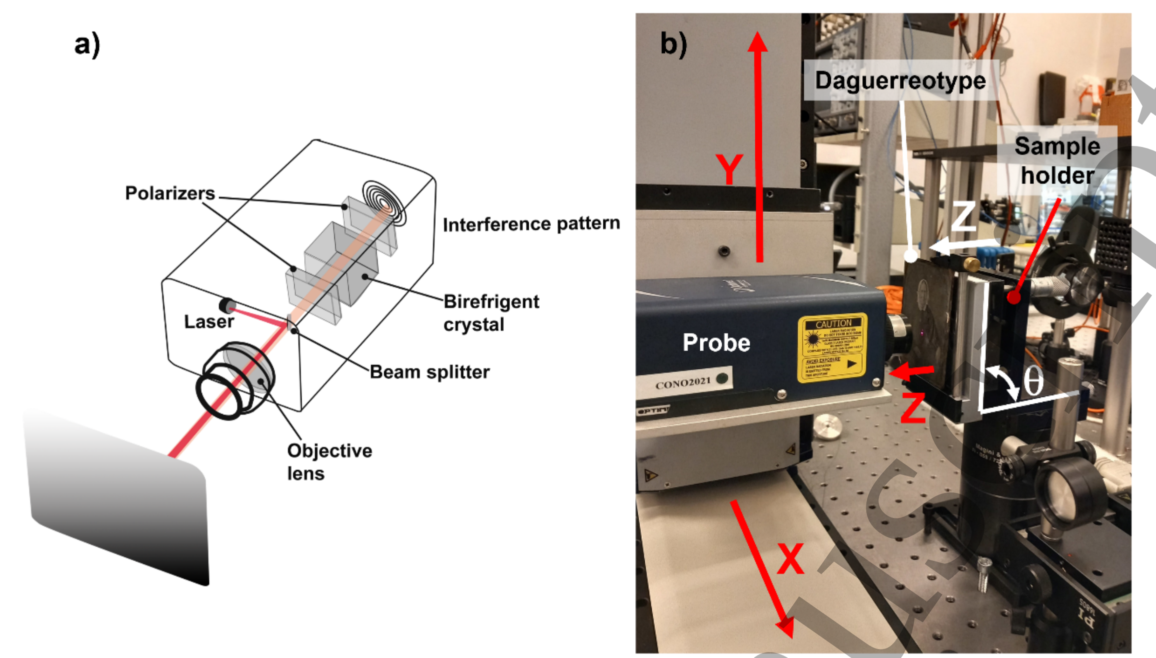

Figure 1. a) Schematic representation of the working principle of the conoscopic holography probe. b) Vertical plane setup with X,Y motorized stages for scanning a daguerreotype plate (534). The sample holder is equipped with a tilter and manual z adjustment (white arrow). Red X,Y,Z arrows indicate positive directions of the coordinate system.

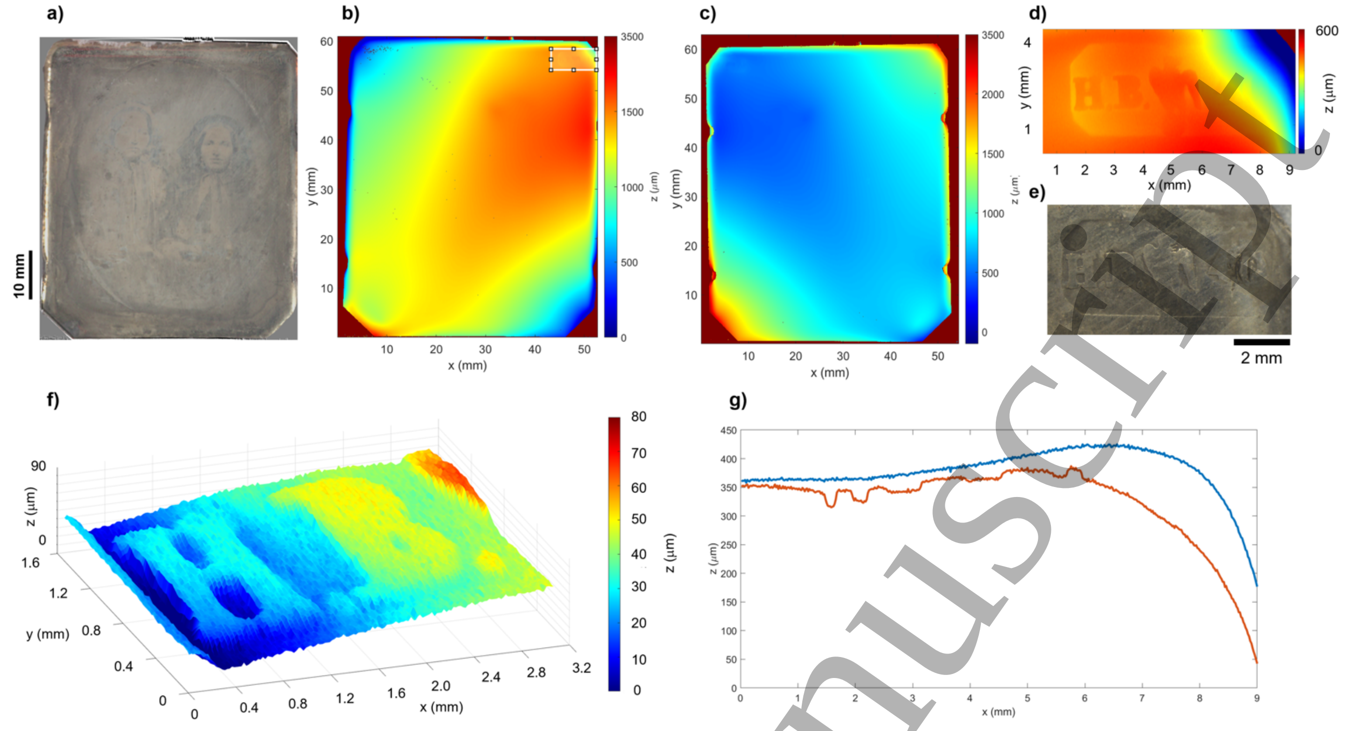

Figure 2. Daguerreotype 519mini: a) visible image (recto), and 2D false color height maps of b) recto and c) verso obtained with the conoscopic holography probe. A detail of the hallmark (marked with a white rectangle in b) is shown in d), the corresponding image obtained with a stereomicroscope is reported in e). f) 3D representation of a detail of the H. B. letters of the hallmark. g) Cross-sectional profiles obtained from two ROIs indicated with the white dashed lines in d); PS and H refer to the plate surface and the hallmark, respectively.

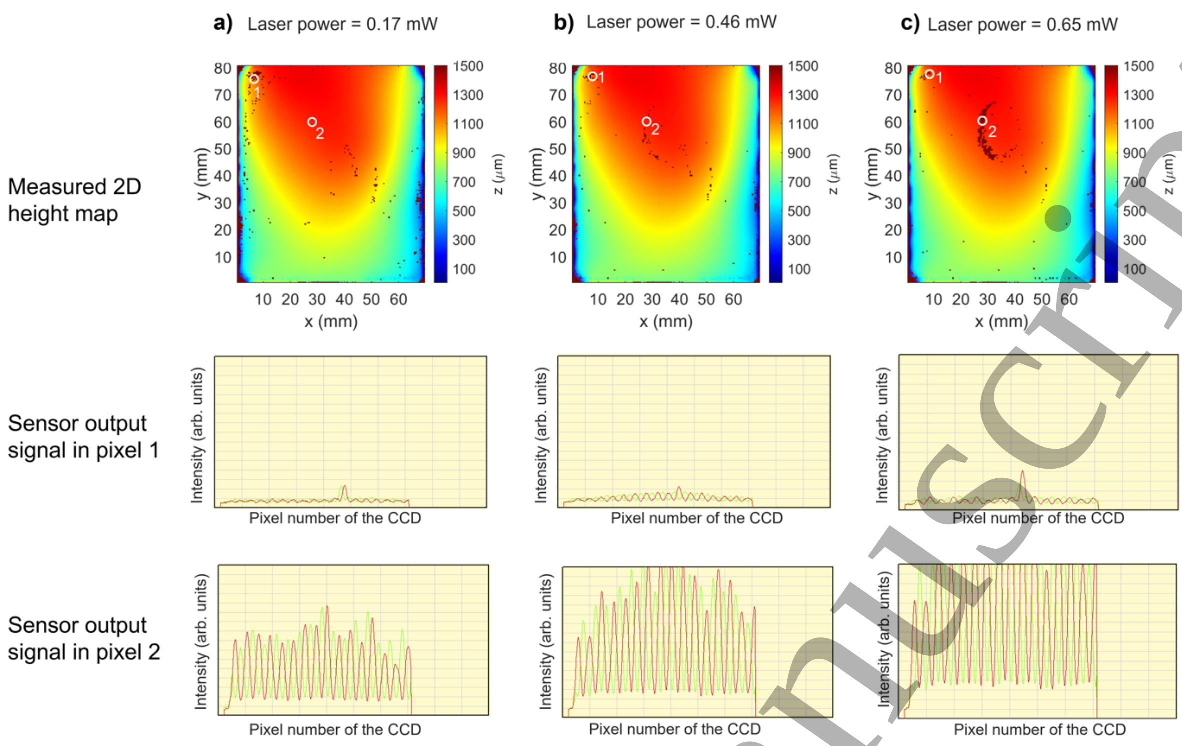

Figure 3. 2D map from the preview performed at a) 0.17 mW, b) 0.46 mW, and c) 0.65 mW. The sensor output (X,Y axes are the same for all the plots) from two different pixels (indicated with a white circles) are reported below the corresponding 2D map.

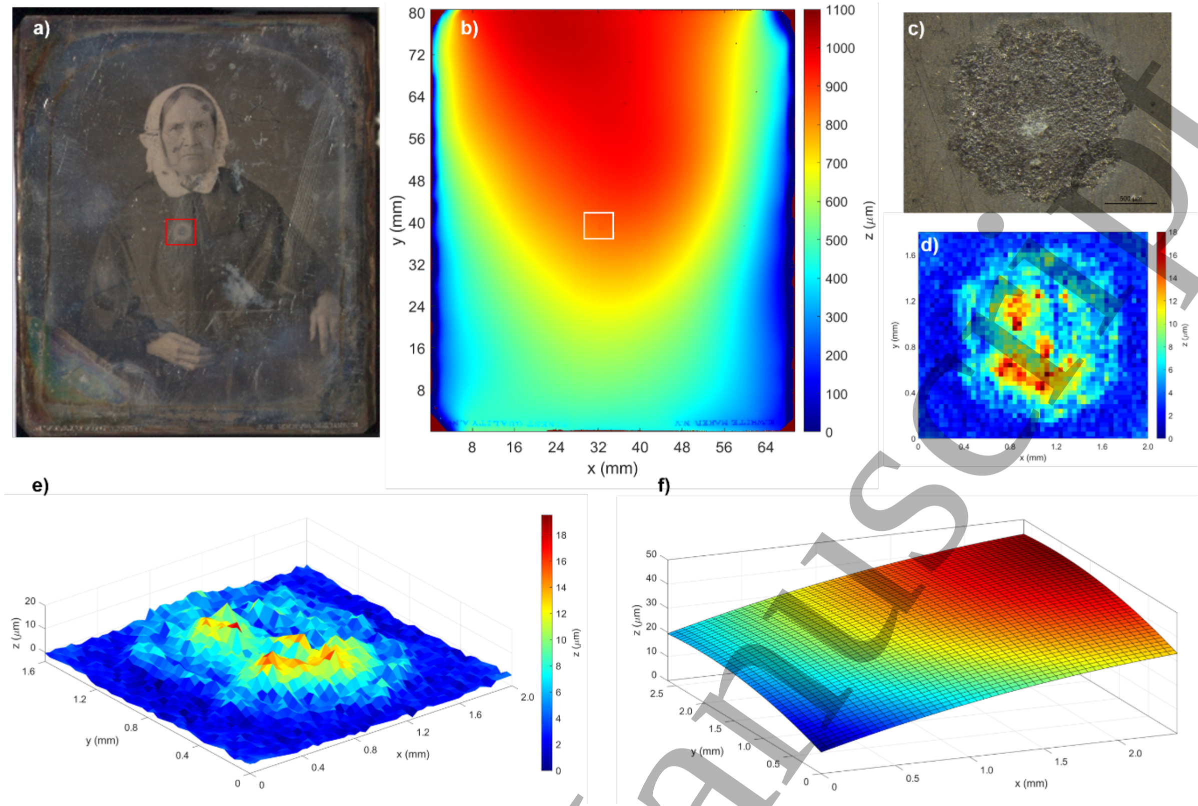

Figure 4. a) Visible image of the verso compared to the b) 2D map from the daguerreotype 534. The red rectangle indicates the ROI, where deposits of copper formates and copper cyanides are located, reported in the c) microphotograph and d) corrected 2D map. The e) 3D map, corrected by subtracting the f) best plane fitted shows the height of the corrosion crystals.

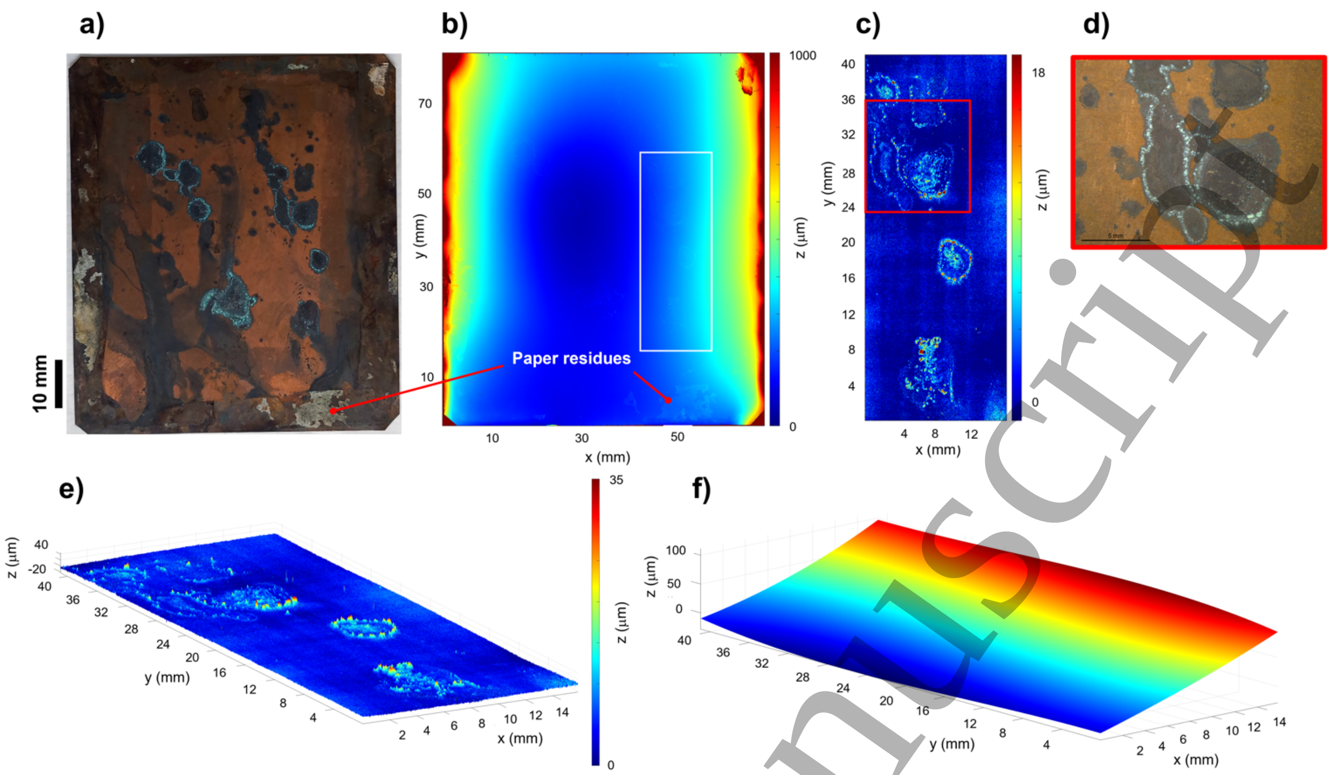

Figure 5. Daguerreotype 534 a) visible image (verso), b) false color 2D map obtained with the double-exposure system. The white rectangle indicates the ROI reported as a 2D map in c) and a 3D map in e) where green corrosion deposits are evident. The microphotography in d) shows a detail from the area indicated with a red rectangle. A best plane fitting (reported in f) and subtraction was applied to enhance the visualization of the morphological features of the corrosion crystals.