9th International Conference on NDT of Art, Jerusalem Israel, 25-30 May 2008
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# OPTICAL AND SURFACE METROLOGY TO STUDY CULTURAL HERITAGE: CONFOCAL TOPOMETRY APPLIED TO THE SURFACE STUDY OF PHOTOGRAPHIC IMAGES

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## ABSTRACT

*Optical and surface metrologies provide non-perturbing (non-contact, non-invasive and non-destructive) instrumental techniques that are amenable and well suited to in situ surface studies of objects of cultural heritage such as original historical and fine art photographs. These innovative non-perturbing topometric technologies provide three dimensional data of the object's surface. They also open a new door and approach to collection-based studies of surfaces of objects of cultural heritage to scholars and researchers, conservators, scientists and engineers.*

*Confocal surface topometry system is being used as research tool in the study of fine art photography from the collection at George Eastman House International Museum of Photography and Film. A research initiative with daguerreotype collections began in late 2005 to establish baselines and condition of the surfaces.*

*Daguerreotypes were the first successful photographic images presented to the world in Paris, 1839. This first form of photography was an instant success, and for 15 years it was the dominant photographic process. Although millions were made during this period of great experimentation, the extreme vulnerability of the image recorded directly on a polished silver plate led to the loss of many of them in a few short years. Those that survive are often deteriorated and still remain highly vulnerable.*

*The conservation treatment of deteriorated daguerreotypes is a challenge. The metallic surface structure defines the image, and until recent technological advances in optical metrology instrumentation, it has not been possible to quantitatively measure the changes in the structure affected by deterioration mechanisms or evaluate restorative conservation treatments. Optical metrology instruments allow for the quantitative examination of the daguerreotype surface's micro and nanostructure. Most significantly, these systems are safe, non-contact and non-destructive. They offer an important advancement in the examination, documentation, and characterization of daguerreotypes in particular, and they can also be applied to the surface analysis of other types of photographs and imaging materials.*

*This presentation will discuss and provide examples of the application of confocal surface topometry system to the examination and assessment of daguerreotypes as well as other photographic media such as silver gelatin photographs.*

## INTRODUCTION

The field of metrology, the scientific study of measurement, and especially that of optical surface metrology is well suited to the study of cultural heritage. Advances in electronics, optics and faster computing in the past ten years have revolutionized the fields of 2D contact surface profilometry and optical and surface metrology. The antiquated surface metrology contact methodologies, which irreversibly perturb surfaces, were never considered by cultural heritage institutions and although still useful in industry are quickly becoming a tool of the past. New optical surface metrology tools such as confocal surface topometry use light to probe surfaces rapidly and risk-free, and yield a wealth of areal data unachievable with 2D contact methods. Such instrumentation enables non-perturbing (non-contact, non-destructive and non-invasive) examination of delicate and sensitive surfaces of the wide range of historic and artistic works encompassing the cultural heritage accumulated by mankind. The new non-perturbing instrumentation presents new approaches and possibilities for collection based studies which were heretofore impossible (Ravines *et al.* 2007; Sotiropoulo and Wei 2006; Wei *et al*. 2005; Grynszpan *et al.* 2004).

Collaboration between the George Eastman House, Conservation Department, and NanoFocus, AG, developer and manufacturer of the µsurf confocal surface topometry systems, has allowed for the successful testing of the µsurf instrument to probe and examine the delicate and sensitive surfaces of numerous types of historical and fine art photographic images. This paper focuses on the application of confocal topometry to the study of daguerreotypes, the first commercially viable photograph making its debut in 1839, and the ubiquitous 20th century silver gelatin photographs. Confocal surface topometry is ideally suited for the examination of the surface geometry of the daguerreotype image independent of the illumination and reflectance factors, thereby providing quantitative metrics of the daguerreotype's surface ultra-fine structure.

**Confocal Principle**

Confocal surface topometry offers the ability to image surface texture thereby allowing one to experience visually the 3D nature of small scale features. The confocal principle was developed in 1955 by Minsky (1988). Minsky's work was not considered seriously until twenty years later, late 1970s, when it was realized that the depth or 'z' resolution is greater than that of optical microscopy, at the expense of a smaller field of view. This optical sectioning or depth-discrimination property of confocal topometry system is its strength: its ability to capture the depth of a sample where the z direction is imaged at various heights and forms a full 3D image from a stack of partial images (Gu 1996; Wilson 2002).

## EXPERIMENTAL METHODS & MATERIALS

In this research a NanoFocus (NanoFocus AG, Lindnerstrasse 98, D-46149 Oberhausen, Germany, info@nanofocus.de) µsurf confocal surface topometry systems was used with 10x and 20x objectives. The confocal system provides 3D surface data arrays of 512 x 512 points for all objectives, represented graphically by contour and isometric maps. A 10x objective with a numerical aperture (NA) of 0.30 and a working distance (WD) of 11 mm provided a 1.55 x 1.55 $mm^2$ measurement field with a vertical resolution of 50 nm; and a 20x objective with NA 0.60, WD 0.9 mm, 800 x 800 $\mu m^2$ field, and vertical resolution 4 nm. µsoft software version 6.1 was used for operation of the confocal topometer, generating contour and isometric images and profiles views. µsoft Analysis Standard software version 4.1 was used for data analysis and calculation of surface texture height parameters: arithmetic mean deviations, Sa, and root-mean-square deviations (RMS), Sq, of the surface. 3D confocal data acquired from the µsurf confocal topometer only provides information on the geometry and physical structure of a surface and not its chemical composition.

This paper presents the studies of one daguerreotype and a set of silver gelatin photographic papers of the same type submitted to different treatment protocols. The daguerreotype from the George Eastman House Department of Photography collections used in this study is the portrait of Boston's notable physician and abolitionist Henry I. Bowditch seated, *c.* 1850, made by the well known Boston daguerreotype studio of Southworth and Hawes is a whole plate measuring 165 x 216 $mm^2$, with catalog number 1974:0193:0043.

The silver gelatin photographic paper studies used Ilford Glossy double weight papers that were fully exposed for maximum density and processed (developed with Kodak Dektol Developer, 90 seconds; Kodak stop bath, 15 to 30 seconds; Kodak Rapid fixer, 8 minutes; final running water wash of 40 minutes; and dried face up). The papers were then subjected to a range of different treatment protocols, see Table 1. Surface changes of these differently treated photographic papers were monitored with the µsurf confocal topometer; 3 to 4 measurements of random locations on each of the treated papers were made, Tables 2a and 2b.

**Table 1: Ilford Glossy Silver Gelatin Double Weight Papers**

| Treatment No | Experimental Protocol |
|---|---|
| 0 | Control, not treated. |
| 1 | Humidified 7 hours at room temperature; dried and flattened in a dry-mount press at 80°C for 1 minute with silicone release paper in contact with silver gelatin emulsion. |
| 2 | Flattened in a dry-mount press at 80°C for 1 minute with silicone release paper in contact with silver gelatin emulsion; no humidification. |
| 3 | Humidified 7 hours at room temperature; dried and flattened at room temperature under weights (5.23 kg) with a polyester non-woven (Hollytex no. 321, 71 µm thickness) in contact with the silver gelatin emulsion. |
| 4 | Humidified 7 hours at room temperature; dried and flattened at room temperature under weights (5.23kg) with a highly calendered paper in contact with the silver gelatin emulsion. |
| 5 | Water immersion for 20 minutes; lined with Dacron cloth and Japanese paper on a rigid Plexiglas support; allowed to air dry for one week before removal from Plexiglas. |
| 6 | Humidified between wet blotters and Gore-Tex sandwich; lined Japanese style and dried emulsion side 'in' on a Karibari drying board. |
| 7 | Water immersion for 2 hours (fully swell gelatin); dried with blotters to remove excess moisture at 10, 20, 30 and 60 minutes; then dried and flattened under pressure for 1 week. |
| 8 | Humidified 7 hours at room temperature; dried and flattened using 42 lbs/19 kg of weights at room temperature with Gore-Tex in contact with the silver gelatin emulsion. |

## RESULTS AND DISCUSSION

The first example of confocal surface topometry system in service of photographic cultural heritage presented is the whole plate daguerreotype made by the studio of Southworth and Hawes of Henry I. Bowditch. This plate was closely examined because of its precarious condition. The second example is the monitoring of surface changes experienced by the series of Ilford Glossy photograph papers subjected to a series of conservation treatments.

### The Henry I. Bowditch Daguerreotype by Southworth and Hawes, *c.* 1850

The Bowditch portrait was examined with stereo and optical microscopy as well as confocal topometry, Figure 1. The plate, Figure 1a, shows numerous yellow-brown stains clearly observable in the white shirt area; and the dark jacket, especially the lower left and right quadrants, and the top right quadrant background show a great number of whitish circular spots likely to be pitting corrosion. The shirt stains in Figure 1b appear to be of two types; three large and one small yellow-brown stain. The large top left stain has a central multicolored circular region within the greater yellow-brown stain, Figure 1c. Generally, stains when on other media such as paper or other cellulosic materials are incorporated into the matrix and do not show surface texture. In this study, this is not the case. Figures 1d, 1e, 2a and 2b demonstrate the considerable three dimensional (3D) nature of the circular region shown in Figure 1c. The circle, in Figure 1c, appears to be a wall-like structure ranging from 50 – 60 µm thick with heights of about 1.2 µm, Figure 2c. Figures 2b and 2c also show the internal circle area to be rougher with large protrusions, whitish areas, and spikes. Figure 2c shows additional subsurface activity; spikes below the surface are evident indicating etching that may have been caused by staining or other material. The reflection view of Figure 2a shows irregular staining beyond the circle, similar to the sun's corona during a solar eclipse, which also has texture although less than that of the circle and inner circle, Figure 2b. Starting at the far left side of the profile through the stain and pit in Figure 2c, the profile shows minimal surface roughness from 0 to 588 µm; beyond 588 µm and into the corona-like stain area, the surface roughness increases slightly until it reaches the wall-like structure of the circle at 800 µm and between the two walls, from 800 to 2000 µm, the surface roughness is greatest.

This case shows confocal topometry to be an ideal tool for the examination and quantitative determination of daguerreotype non-image surface features. This technology allows researchers to acquire accurate 3D data of the daguerreotype surface. This information directly adds significant technical information to understanding this earliest photographic process, and provides critical data for monitoring condition changes over time.

Figure 1a. Henry I. Bowditch, c. 1850, Southworth and Hawes, whole plate daguerreotype (165 x 215 mm$^2$). Note lower half is affected by yellow/brown staining and pitting corrosion.

Figure 1b. Detail of shirt staining.

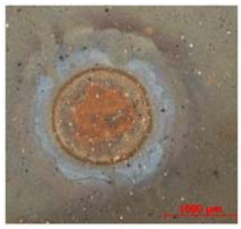


Figure 1c. Detail of top left stain, stereo microscope mag. 20x.

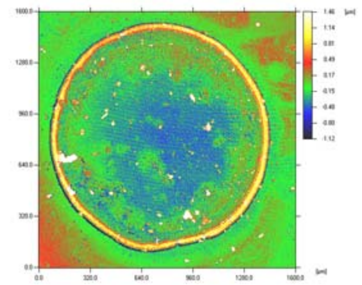

Figure 1d. Contour view of 3D confocal data in false color of top left stain demonstrating its topographical nature. Field of view 1.6 x 1.6 mm$^2$, objective 10x, height range -1.12 to 1.46 µm.

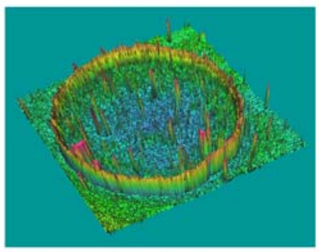

Figure 1e. Isometric view of confocal data in false color of top left stain in 1c & 1d clearly showing its 3D nature. Details as in 1d.

*Figure 1. Whole plate daguerreotype of Henry I. Bowditch taken by the famous Boston photographers/ daguerreotypists of Southworth and Hawes, c. 1850, from George Eastman House International Museum of Photography and Film collection.*

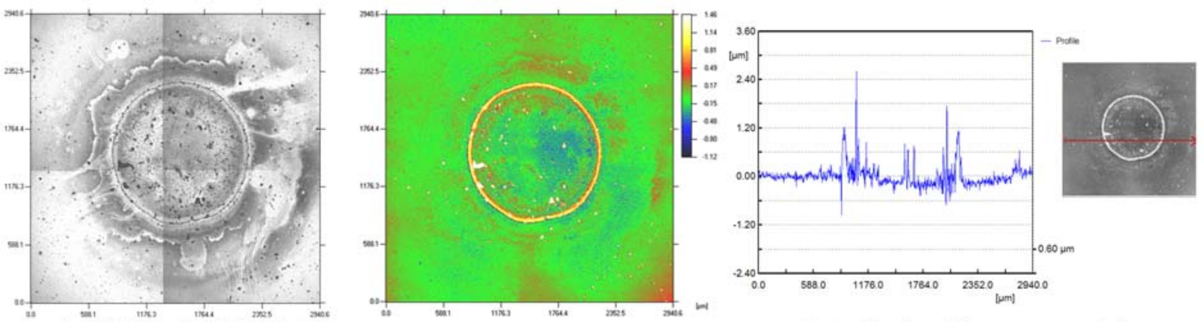


Figure 2a. Reflection/confocal bright field view of 2 x 2 stitched tile array of the stain showing its lateral expansiveness. Objective 10x, field of view of 2 x 2 mosaic 2.94 x 2.94 mm$^2$.

Figure 2b. Contour view in false color of 2a. Objective 10x, field of view of array 2.94 x 2.94 mm , height range -1.12 to 1.46 µm.

Figure 2c. Profile through lower portion of the stain (red line) showing outer and inner differences in surface roughness and subsurface stain etching.

*Figure 2. Examination and topographic analysis of a circular spot in the middle of a yellowish shirt stain on Henry I. Bowditch.*

**Silver Gelatin – Ilford Glossy Paper Treatment**

The surfaces changes of the Ilford Glossy double weight silver gelatin photograph papers subjected to eight different humidification, wetting, flattening and drying treatment protocols described in Table 1 were monitored with the µsurf confocal topometer. Visual display of the 3D surface height data are presented for three of the nine samples to showcase the nature and quality of the information gleaned from highly glossy and low surface textured samples. The three samples shown in figure 3 are: control, no treatment or protocol 0; treatment protocol 1, humidification for 7 hours then flattening and drying in a dry-mount press heated to 80°C for one minute; and treatment protocol 7, immersion in water for two hours then dried with blotters to remove excess moisture at 10, 20, 30 and 60 minutes, and finally dried and flattened under pressure for 1 week. Surface roughness height parameter averages and standard deviations of arithmetic mean deviation of the surface, Sa, and the root mean square deviation of the surface, Sq, are presented in Tables 2a and 2b. The averages for Sa and Sq are plotted as a function of treatment protocol in Figure 4.

Figures 3a shows the reflection view of the control which has prominent dark spots well distributed throughout the field of view. The 3D surface height data is plotted in Figure 3b in an isometric view; it also shows an even distribution of pits which would correspond to the dark spots in the reflection view, Figure 3a; and it shows the waviness of the glossy surface which is not evident in the reflection view. Table 2a, column '0', lists the Sa (arithmetic mean deviation) values of the control paper three areas sampled (using a Gaussian 80 µm filter) along with the Sa average and standard deviation. These Sa values describe a homogeneous surface with an average Sa of 0.100 µm and standard deviation of 0.001 µm. The Sq values also demonstrate the homogeneity of the surface.

The reflection and isometric views of the paper humidified for 7 hours and dried in a heated dry-mount press at 80°C are shown in Figures 3c and 3d. This specific treatment has considerably affected the gelatin surface as observed in the reflection view, Figure 3c, which looks different than Figure 3a. The isometric view, Figure 3d, is also different than Figure 3b. The dark spots in the reflection view and the pits in the isometric view are no longer present and the overall look is 'smoother'. The average Sa and Sq values confirm this as well; they have decreased by about 6 to 7% yet their corresponding standard deviations are greater than the control's. Although, the overall look is 'smoother' according to average Sa, the homogeneity of the surface has decreased as evaluated by the standard deviation. Flattening a humidified photographic paper with heat and pressure has allowed the gelatin surface to be reformed as observed by the almost complete eradication of dark spots and pits.

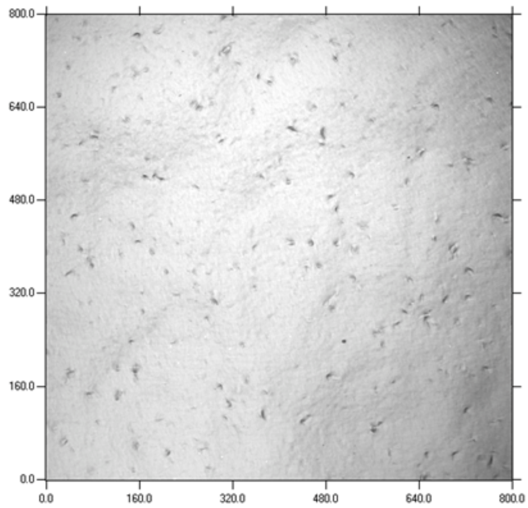


Figure 3a. Reflection/confocal bright field view of Ilford Glossy photographic paper 'control' surface. Control: paper was exposed, developed and fixed. Objective 20x, field of view 800 x 800 μm².

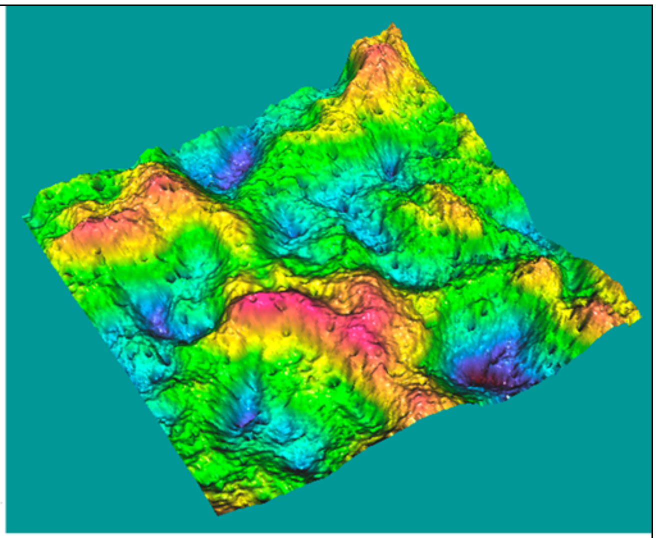

Figure 3b. Isometric view of 3a in false color showing overall surface texture and even distribution of pits. Pits correspond to dark spots in 3a. Objective 20x, field of view 800 x 800 μm², height range -3.00 to 2.40 μm.

*Figures 3a & 3b. Reflection and isometric views of Ilford Glossy papers subjected to different treatment protocols.*

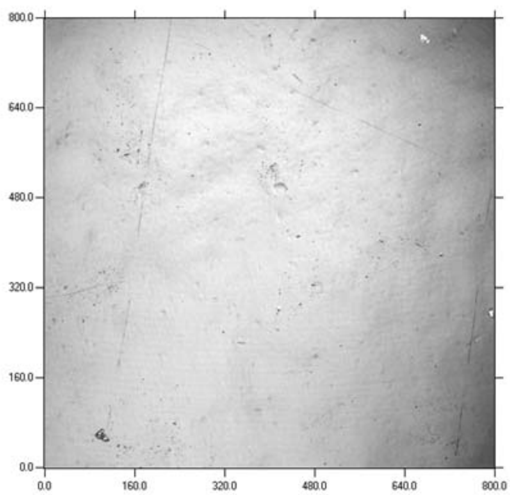


Figure 3c. Reflection/confocal bright field view of Ilford Glossy paper surface after humidification for 7 hours, dried and flattened in a heated, 80°C, dry mount press. Pitting has been removed.

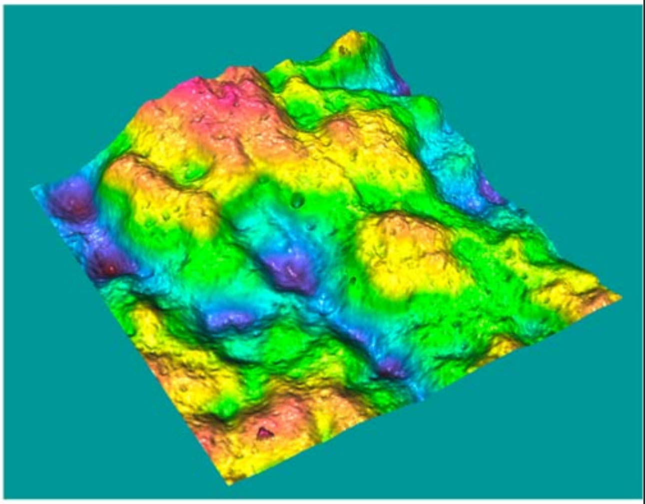

Figure 3d. Isometric view of 3c in false color showing surface changes after humidification and drying; an increase in roughness and fewer pits remain. Height range -3.10 to 2.47 μm.

*Figures 3c & 3d. Reflection and isometric views of Ilford Glossy papers subjected to different treatment protocols.*

After immersing this photographic paper in water for 2 hours permitted the gelatin to fully swell, then drying between blotters and a polyester non-woven (Hollytex) dark spots and pits are still present, Figures 3e and 3f, and additional markings; four on the left and one in the lower right have appeared. Note that the height range for Figure 3f is considerably greater than in the two previous examples. These markings appear to be from the polyester non-woven that was in contact with the gelatin surface during the pressing and drying process. The arithmetic mean deviation, Sa, and the RMS deviations, Sq, have increased by 15 to 30%: Sa (control) = 0.108 μm to Sa (treatment 7) = 0.126 μm; and Sq (control) = 0.141 μm to Sq (treatment 7) = 0.194 μm. The overall surface topographical height parameters, Sa and Sq, have been affected by this treatment protocol and it may be attributed to the long 2 hour soak allowing the gelatin to fully swell.

Height parameter Sa and Sq values per sampled area, averages and standard deviations are presented in Tables 2a and 2b. Figure 4 shows the height parameter averages plotted as a function of treatment protocol. Of all the treatments protocols the Ilford Glossy photographic papers were subjected to, treatments number 6 (humidification and lining) and 7 (immersion in water) resulted in the greatest alterations of the glossy gelatin surface texture. Humidification treatments 2, 3, 4 and 8, and, treatment 5, a quick 20 minute immersion in water, appear to have had a minimal effect on the glossy gelatin surface texture. Interestingly and as mentioned earlier, treatment protocol 1, humidification for 7 hours and dry-mount press flattening at 80°C, resulted in decreases in both height parameters and provided a 'smoother' look by having removed dark spots and pits in the reflection and isometric views, Figure 3c and 3d. The results of this protocol are unique; it has had a reverse or contrary effect compared to all other treatments.

The high level of surface detail that topometry measurements provided the conservator will allow monitoring and evaluation of surface changes that are at two levels; a level beyond human visual detection, and at the observable level. Perhaps this powerful technique could assist conservators to learn to effect necessary conservation changes to historic and artistic photographic works below human visual detection levels.

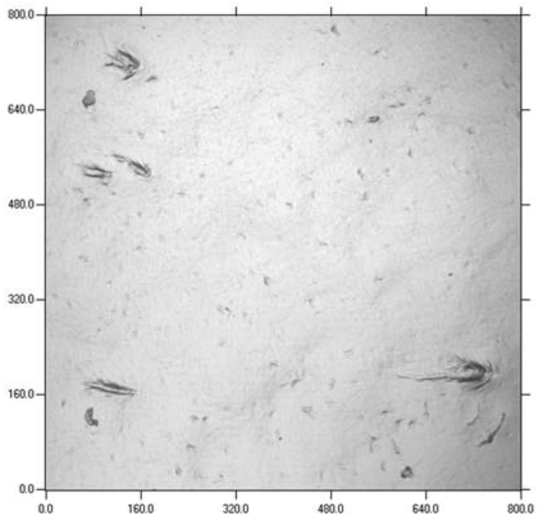


Figure 3e. Reflection/confocal bright field view of Ilford Glossy paper surface after immersion water and dried between blotters. Pitting is still visible and additional markings from drying process are evident.

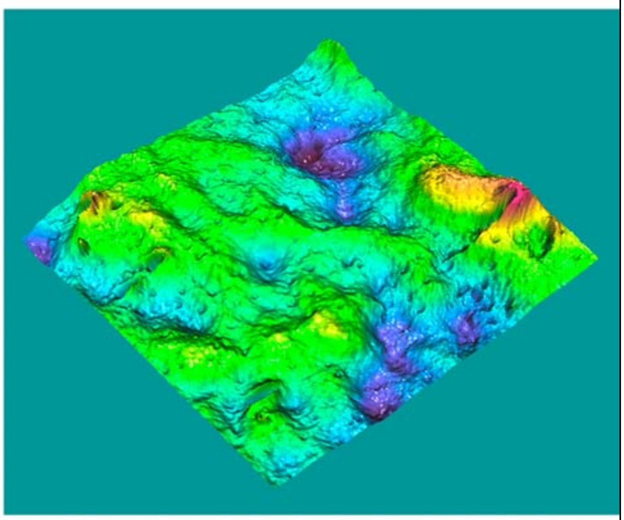

Figure 3f. Isometric view of 3e in false color showing surface changes after immersion in water and dried between blotters. As in 3e, pits and treatment markings are clearly visible. Height range -4.45 to 4.50.

*Figures 3e & 3f. Reflection and isometric views of Ilford Glossy papers subjected to different treatment protocols.*

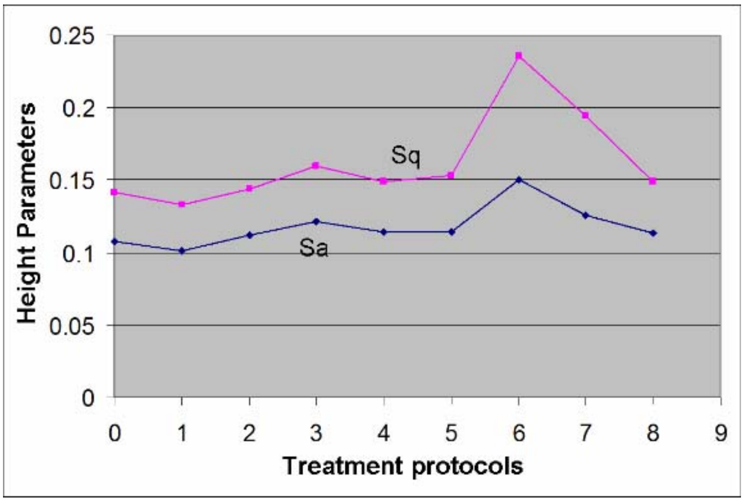


*Figure 4. Height parameter averages, Sa and Sq, plotted as a function of treatment protocol.*

| Table 2a: Sa, Arithmetic Mean Deviation of the Surface using a roughness filter, Gaussian 80 µm; (all measurements in µm.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment ▶ Measurement ▼ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 0.107 | - | - | 0.132 | 0.121 | 0.120 | 0.169 | 0.141 | 0.112 |
| 1a | - | 0.0982 | 0.113 | - | - | - | - | 0.116 | 0.116 |
| 2 | 0.108 | 0.0883 | 0.115 | 0.111 | 0.105 | 0.116 | 0.165 | 0.130 | 0.11 |
| 3 | 0.109 | 0.114 | 0.108 | 0.121 | 0.116 | 0.107 | 0.117 | 0.117 | 0.115 |
| 4 | - | 0.104 | - | - | - | - | - | - | - |
| Average (µm) | 0.108 | 0.101 | 0.112 | 0.121 | 0.114 | 0.114 | 0.150 | 0.126 | 0.113 |
| Std. Deviation (+) | 0.001 | 0.014 | 0.004 | 0.011 | 0.008 | 0.007 | 0.029 | 0.012 | 0.003 |

| Table 2b: Sq, Root-Mean-Square Deviation of the Surface using a roughness filter, Gaussian 80 µm (all measurements in µm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment ▶ Measurement ▼ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 0.139 | - | - | 0.174 | 0.156 | 0.168 | 0.276 | 0.237 | 0.150 |
| 1a | - | 0.124 | 0.144 | - | - | - | - | 0.183 | 0.147 |
| 2 | 0.138 | 0.119 | 0.149 | 0.145 | 0.134 | 0.151 | 0.276 | 0.195 | 0.145 |
| 3 | 0.147 | 0.149 | 0.138 | 0.161 | 0.156 | 0.140 | 0.155 | 0.162 | 0.152 |
| 4 | - | 0.139 | - | - | - | - | - | - | - |
| Average (µm) | 0.141 | 0.133 | 0.144 | 0.160 | 0.149 | 0.153 | 0.236 | 0.194 | 0.149 |
| Std. Deviation(+) | 0.005 | 0.014 | 0.006 | 0.015 | 0.013 | 0.014 | 0.070 | 0.032 | 0.003 |

**CONCLUSIONS**

The optical and surface metrological technique of confocal topometry is a non-perturbing (non-contact, non-invasive and non-destructive) instrumental method that has shown its potential to *in situ* document and measure changes of the ultra-fine surface structure of the daguerreotype. Perhaps the most important feature of the 3D topographical data of a daguerreotype is the direct correlation between the image and alteration or damage to the surface structure. It is this direct relationship that makes the confocal topometry a powerful, perhaps essential, instrument in the latest research on the science and conservation of daguerreotypes.

The confocal example of the surface blemish on the daguerreotype of Henry I. Bowditch presented is one of many areas examined with the goal of establishing a quantitative baseline reference to be continually monitored in the future. Any measurable surface changes that the object undergoes detected by confocal topometry system could be attributed to an inhospitable environment. Metrics of this nature convert the historic and artistic object into a sensor of its environment and could allow for the development of a 'surface health index' of objects in collections.

The surfaces changes of the Ilford Glossy silver gelatin photograph papers monitored with the µsurf confocal topometer clearly demonstrate its ability to follow fine changes effected through conservation treatments, and the value of quantitative surface data and information obtained from highly glossy and low surface textured materials. This instrumental technique has many potential applications globally for the conservation and restoration of photographs in which fine surface features and smooth glossy surfaces are defining characteristics. Optical surface metrology especially shows promise for quantitative evaluation of treatment regimens, and for condition monitoring of photographs in storage or on loan over term periods.

Conservators will always rely on visual qualitative methods to evaluate condition and the effects of treatment, yet research information derived from 3D quantitative surface studies can significantly advance the field and further train the already keen eye of the conservator and restorer.

**ACKNOWLEDGEMENTS**

P. Ravines acknowledges the Andrew W. Mellon Foundation for support through the Advanced Residency Program (ARP) in Photograph Conservation; Ralph Wiegandt, Assistant Director ARP at George Eastman House; and Hans Hermann Schreier, President and CEO NanoFocus AG.

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