Journal of Cultural Heritage 66 (2024) 110–116

Contents lists available at ScienceDirect

Journal of Cultural Heritage

journal homepage: www.elsevier.com/locate/culher

VSI: TECHNART 2023 selected papers

Integrated microprofilometry and multispectral imaging for full-field analysis of ancient manuscripts

S. Mazzocato, D. Cimino, C. Daffara*

Computer Science Department, University of Verona, Strada Le Grazie 15, Verona, 37134, Italy

ARTICLE INFO

Article history:
Received 21 August 2023
Accepted 16 November 2023

Keywords:
Optical profilometry
Surface analysis
Multispectral imaging
Integrated diagnostics
Ancient manuscript

ABSTRACT

A novel workflow is proposed to combine the use of two powerful techniques in the study of ancient manuscripts: multispectral imaging and optical microprofilometry. Multispectral imaging is routinely used and allows to examine each individual *folium* as a superposition of layers that give different responses in the UV-Vis-NIR bands. It enables the analysis of the conservation state of an object, the mapping of previous restorations or the detection of writings no longer visible. The downside of this technique is the lack of quantitative data on surface morphology. On the other hand, surface microprofilometry on book heritage is unexplored. The optical scanning microprofilometer used in this work employs single-point, interferometric depth-sensors that enable to measure the surface topography of the manuscript (deformation and roughness) in full-field (areas of tens of centimeters) at micrometer scale. The crucial task of spatial referencing the surface topography at micrometer scale to the visible features (e.g., written text) is performed with a novel procedure that solves the problem of the lack of reference points in the microprofilometer height data. We exploit the raw intensity signal collected by the laser depth sensor to fuse the interferometric measurements with the multispectral image stack. The full-field integration of quantitative microsurface measurements and in-band imaging responses enables a more comprehensive exploration of ancient manuscripts, by integrating materials-surface analysis, advancing the diagnostic protocol.

1. Introduction and research aim

The study of ancient manuscripts holds the key to understanding our rich historical heritage and unlocking the mysteries of these seemingly silent witnesses of the past. However, the passage of centuries has taken a toll on these fragile artifacts, leaving researchers with the daunting challenge of deciphering their content and preserving their delicate essence. In fact, the library heritage consists of fragile materials, such as parchment, papyrus, and paper, which are very responsive to moisture, light, heat and mechanical stresses and thus to the process of degradation [1–3]. A common approach in the analysis of cultural heritage and ancient manuscripts in particular is the use of multispectral imaging (MSI) as reported in a recent review [4]. Several MSI acquisition systems are currently available to investigate book heritage thanks to the possibility of acquiring high-resolution images using monochromatic sources in the ultraviolet (UV), visible (Vis), and near-infrared (NIR, 800 nm to 1100 nm) spectral range and high-performance sensors. A review of commercial systems for historical document image analysis is given in [5]. The capabilities of the different wavelengths to penetrate the different layers and bringing to light varnishes, retouching and faded text (by UV) or underwriting and underdrawings (by NIR) is well-known [6,7]. In addition, the use of narrowband LED sources allows smaller spectral features to be distinguished, increasing the diagnostic values of the analysis [8] and constituting a precious dataset for image processing [4,5,9]. Recently, the short-wave-infrared (SWIR, 0.7 μm to 1.7 μm) and the mid-wave-infrared (MWIR, 3 μm to 5 μm) have been integrated in the UV-Vis-NIR imaging protocol of manuscripts to improve materials investigation [10].

Nevertheless, the imaging information cannot be disentangled from surface morphology that influences the scattering. For this reason, in this paper, we explore the scientific analysis of ancient manuscripts from a slightly different perspective: the quantitative microsurface perspective. Our investigation will delve into the integration of full-field surface analysis in the image-based diagnostic protocol, which is, to the best of our knowledge, an unexplored technique in the field of book heritage analysis. An earlier attempt

* Corresponding author.
E-mail address: claudia.daffara@univr.it (C. Daffara).

https://doi.org/10.1016/j.culher.2023.11.014

to combine imaging and the 3D model of the surface can be found in [11], where the shape of surface, obtained by structured light, is used to correct the geometric distortions. Instead, the focus of the present paper is on the micrometer scale of the texture and not on the large scale of the *folium* deformation. Literature reports the use of scanning electron microscopy (SEM) [3,12] and atomic force microscopy (AFM) [13] images for qualitative analysis of surface morphology at sub-micrometer scale in parchments, while quantitative analysis of the micro-roughness is performed in small samples by contact stylus-based profilometers for evaluating the cleaning of ancient paper [14]. Contact profilometry was also applied to samples of palm leaf manuscripts for text feature analysis [15]. Full-field monitoring is performed at larger scales, using 3D digital image correlation (DIC) for monitoring sub-millimeter humidity-induced deformation in parchments [16]. In [17] there is the first application of the conoscopic holography to analyze the superposed strokes for forensic purposes. The reason behind the non-use of surface metrology on book heritage is straightforward: besides the need for non-contact microprofilometers with full-field capability, the lack of landmarks in the surface that makes the interpretation difficult. In fact, from the three-dimensional point of view, each single *folium* is a very flat surface composed by a substrate (e.g. parchment, paper) and subtle relief or engraved traces produced while writing the text that differ depending on the technique used (handwriting with different tools or printing process).

Our group has dedicated strong research efforts to demonstrate the potentiality of surface microprofilometry for artworks applications by developing a portable laser scanner profilometer based on interferometric sensors that enables a whole-field contactless measurement. This profilometer allows the acquisition of the surface morphology in macro-regions (tens of centimetres) with micrometer accuracy. The potentialities of microsurface analysis were demonstrated on the monitoring of painting treatment by surface metrology based on ISO standard descriptors [18] and performing a multiscale roughness analysis to validate innovative cleaning treatments of highly reflective artworks [19]. Recently, we proposed a new methodology to solve the problem of the spatial referencing of microsurface dataset [20] by exploiting the capability of the conoscopic holography sensors to record a dual intrinsically registered dataset composed by the height data and intensity data (i.e., the backscattered signal of the laser diode).

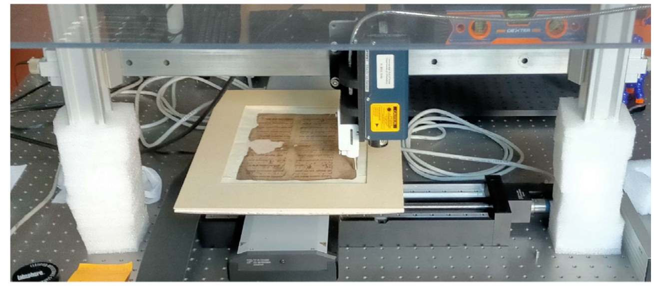
Starting from this last research strength, the research aim of this work is the development of a data fusion methodology that enables the registration of the microsurface dataset with respect to the MSI dataset to perform a full-field analysis of ancient manuscripts. In fact, despite the potential and the strengths of the MSI, the third dimension, i.e. the surface height dimension, is missing. Here we demonstrate how the joint used of the surface dataset combined with MSI dataset offers a new way to explore such fragile objects and can be a guide in the preservation processes: on the one hand the MSI allows to discriminate the different features, on the other hand the surface analysis allows to detect the modifications of the roughness, to inspect texture non-homogeneity, and to retrieve the traces left on the support. Micrometer-scale registration of the microprofilometry and imaging datasets allows for a match between the spectral and microsurface fingerprints.

2. Materials and methods

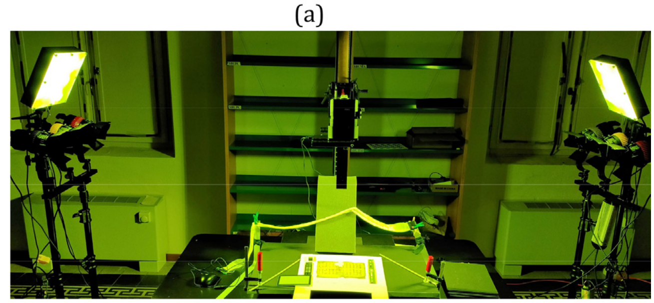
2.1. Instrumentation

2.1.1. The optical scanner microprofilometer

The microprofilometer is a prototype composed by a scanning system of linear stages (M-531.DDB and M-414.3DG by Physik Instrumente) orthogonally mounted combined with a depth sensor probe based on the conoscopic holography (ConoPoint-3 by Optimet). An exhaustive description of the instrument can be found in [18]. Here, the setup was optimized to answer the needs of book heritage applications in terms of scan dimension and spatial resolution, see Fig. 1. In detail, the conoscopic holography is an interferometric technique implemented in a probe, based on a laser diode of 655 nm, that performs single-point distance measurements in the line-of-sight direction. Thanks to the combination with the linear stages the prototype can acquire large areas up to 30 cm×30 cm (i.e., the travel range). The scan step can be chosen and guided by requirements and the spot size of the laser, maintaining a high resolution and accuracy both in the depth (order of sub-micrometers) and lateral (order of micrometers) directions. In this work the x-y spatial step was set at 10 µm, employing the 50mm focal lens that allows to achieve a depth accuracy of 2.5 µm. If a surface is viewed as a 2D continuous function of height, then the measurement performed by the optical scanner microprofilometer can be considered the discrete sampling of the selected Region of Interest (ROI) performed with a spatial x-y grid given by the scanning step. As shown in [20], the datasets obtained from the interferometric sensor probe are threefold:



(a)



(b)

Fig. 1. (a) Microprofilometer optimized to scan the ancient texts. If necessary, an optical fiber (shown in the setup) can be mounted jointly with the probe to acquire referenced spectra. (b) Phase One RAINBOW system.

1. Surface height data, $z_{x,y}$: interferometric data reporting the distance between the object and the sensor.
2. Signal-to-noise ratio (SNR), $snr_{x,y}$: dataset with the signal quality of each measured point.
3. Total, $t_{x,y}$: energy collected by the detector (raw intensity signal in arbitrary unit).

Each experimental dataset is a set of three surface maps intrinsically spatially registered with micrometer precision and enclosing different information.

2.1.2. Multispectral imaging system

The multispectral stack is composed by 16 images in the UV-Vis-NIR range acquired using the Phase One RAINBOW system equipped with an iXG 100MP Wide Spectrum camera (Si CMOS sensor, 350 µm to 1050 µm). In detail, the system employs LED lights that provide 16 narrowbands in the following wavelengths:

365 nm, 385 nm, 410 nm, 420 nm, 450 nm, 480 nm, 510 nm, 530 nm, 550 nm, 600 nm, 630 nm, 640 nm, 660 nm, 740 nm, 850 nm and 940 nm. The filter wheel and a Schneider Kreuznach RS 72mm lens were mounted on a reprographic column. In-scene standards were used during the acquisition: a GoldenThread/DICE Device Level Target (DLT) and an Object-Level Target by Image Science Associates using Vis light and the Target UV by UV Innovations™ for UV images. The images were calibrated using Capture ONE 20 by PhaseONE and Rainbow MSI software.

2.2. Spatial registration methodology

The spatial registration of the imaging stack and the surface height map is based on a recent and novel methodology proposed by the authors in [20] and expanded here to the MSI dataset. The process exploits the raw intensity dataset Total to solve the problem of spatial registration and data fusion in microprofilometry and to perfom supervised and precision diagnostic tasks not otherwise possible. The spatial registration, exemplified in the flowchart of Fig. 2, can be summarized in the following steps:

1. All the images of the multispectral stack are registered to each other. This step is necessary to correct unavoidable misalignments.
2. The images are resampled in order to have the same number of points of the surface data.
3. The Total map $t_{x,y}$ is used as intensity-based image to be registered to the multispectral stack. In detail, the geometrical transformation is calculated allowing in-plane registration of the total map $t_{x,y}$ and the image taken at the closest wavelength to that of the laser (660 nm). The registration is performed though the Matlab algorithm `imregister` [21].
4. The geometric transformation found is then applied to the entire multispectral stack to obtain a new, more comprehensive dataset consisting of the multispectral data and the surface data fully spatially registered.

This procedure enables to obtain a full-field multispectral-height dataset that can guide the analysis.

2.3. Surface metrology descriptors

The quantitative surface inspection is performed by means of surface metrology descriptors estimated on the sampling areas segmented through the MSI dataset as explained in Section 3. Table 1 describes the parameters used in this work, while an extended description of the general parameters and their suggested use in cultural heritage can be found in literature [18,22].

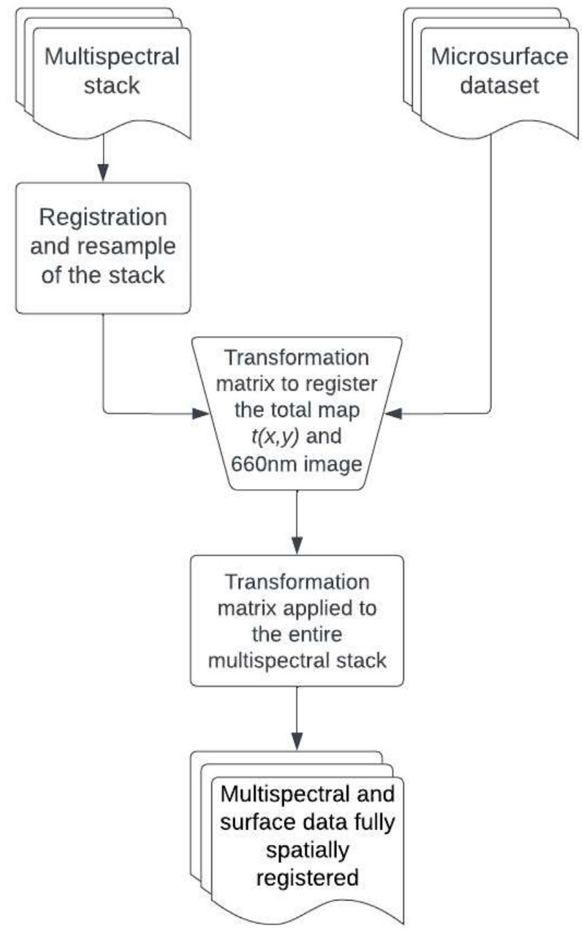


Fig. 2. Flowchart of the proposed spatial registration of image stack and microsurface dataset.

3. Results and discussion

The proof of concept case study is given on a *folium* of private collection reporting a musical notation, depicted in Fig. 3. It is written on paper, with different inks that distinguish notes from text and highlight capital letters, in particular black, red, and yellow. Unfortunately, when found, it was the cover of a prayer book, thus decontextualized from its original function. It has been recently restored, even though it is possible to observe darken areas and slightly faded text due to partial degradation of the substrate and the inks.

Table 1
Amplitude and hybrid Parameters, from ISO 25178-2 standard, used in this work. The notation $\frac{dz_{x,y}}{dx}$ and $\frac{dz_{x,y}}{dy}$ indicates the discrete partial derivatives along x and y respectively, where $z_{x,y}$ is the surface height data.

Parameters	Description
RMS roughness $Sq = \sqrt{\frac{1}{n_x n_y}\sum_{x=1}^{n_x}\sum_{y=1}^{n_y} z_{x,y}^2}$	Amplitude parameter. It describes the mean height of the surface texture.
Slope or RMS gradient $Sdq = \sqrt{\frac{1}{n_x n_y}\sum_{x=1}^{n_x}\sum_{y=1}^{n_y}\left[(\frac{dz_{x,y}}{dx})^2 + (\frac{dz_{x,y}}{dy})^2\right]}$	Hybrid parameter. It can be used to inspect the surface anisotropy.
Developed interfacial area ratio $Sdr = \frac{1}{n_x n_y}\sum_{x=1}^{n_x}\sum_{y=1}^{n_y}\left[\sqrt{1 + (\frac{dz_{x,y}}{dx})^2 + (\frac{dz_{x,y}}{dy})^2} - 1\right]$	Hybrid parameter. It estimates the surface complexity.

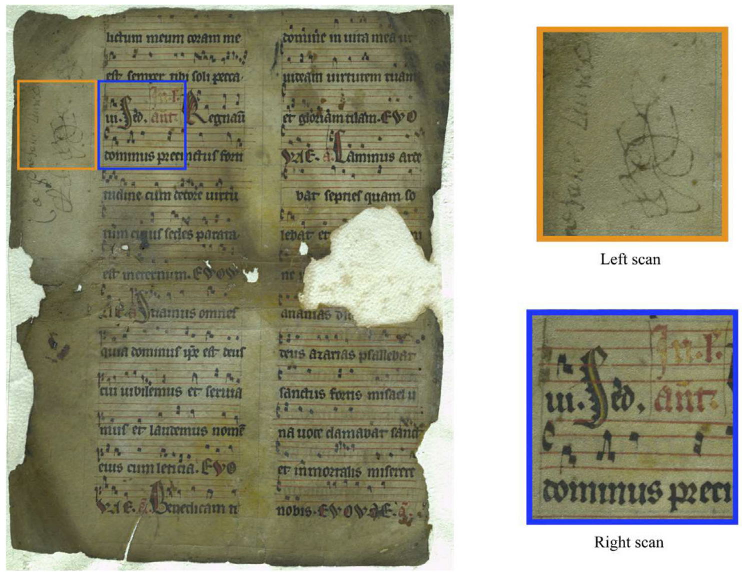


Fig. 3. Visible image of the *folium* with the two selected areas (left scan and right scan) highlighted in orange and blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

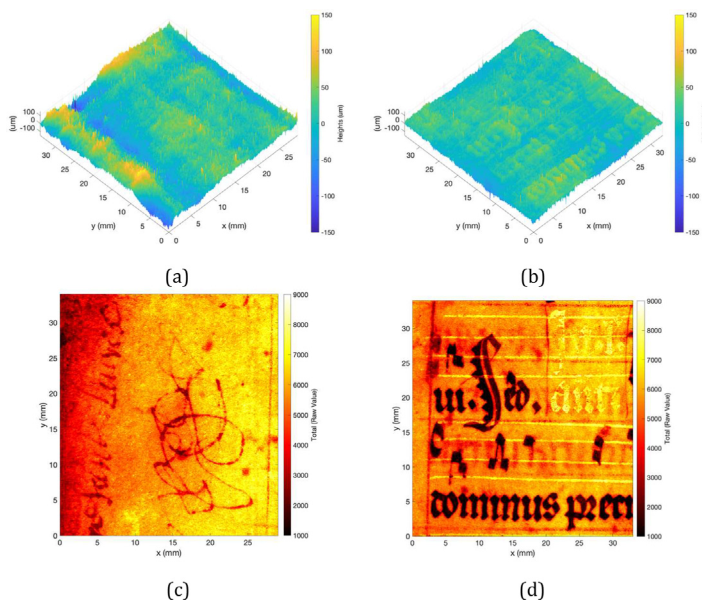


Fig. 4. Microprofilometer datasets acquisition of the two scans. (a)-(b) Surface texture maps $z_{x,y}$ and (c)-(d) Total maps $t_{x,y}$.

3.1. The microsurface dataset

Fig. 4(a) and (b) show the three-dimensional topography maps obtained from the surface height datasets. These maps show the texture of the manuscript once the form is removed. The quality of each measurement is assessed by ensuring the correct working distance according to the lens-probe coupling (working range of 2 mm) and a proper response of the laser according to the different materials (paper, inks).

As can be seen, the microprofilometer effectively acquired the surface, but the lack of references in the height maps is an obstacle for a meaningful and supervised analysis of the surfaces. From this fact emerges the importance of using the Total maps that make the surface visually readable, see Fig. 4(c) and (d).

On the other hand, Total maps contain information based on laser intensities after backscattering of the 655 nm beam from the surface. This implies that the material response is specific for this wavelength. Therefore, mapping the multispectral dataset onto the surface enables a guided surface inspection, leading to a comprehensive full-field analysis of the manuscript.

3.2. The dual height-imaging dataset

The left scan gave the opportunity to study the external edge of the *folium*, typically the most fragile part as it is most exposed to the external environment, used for annotations or touched. Fig. 5(a)–(d) show the UV imaging (365 nm), the IR imaging (850 nm), and the surface map spatially registered at micrometer scale. The MSI dataset was calibrated and converted in reflectance values using an in-scene certified reflectance standard.

In general, UV-based imaging enables the detection of faded inks, retouchings, and varnish non-homogeneity. UV radiation interacts mainly with the most superficial layers and thus, in principle, with the surface sampled by the microprofilometer. On the other hand, the IR radiation penetrates the first layers and brings to light features that are not visible. In this case, the writing results

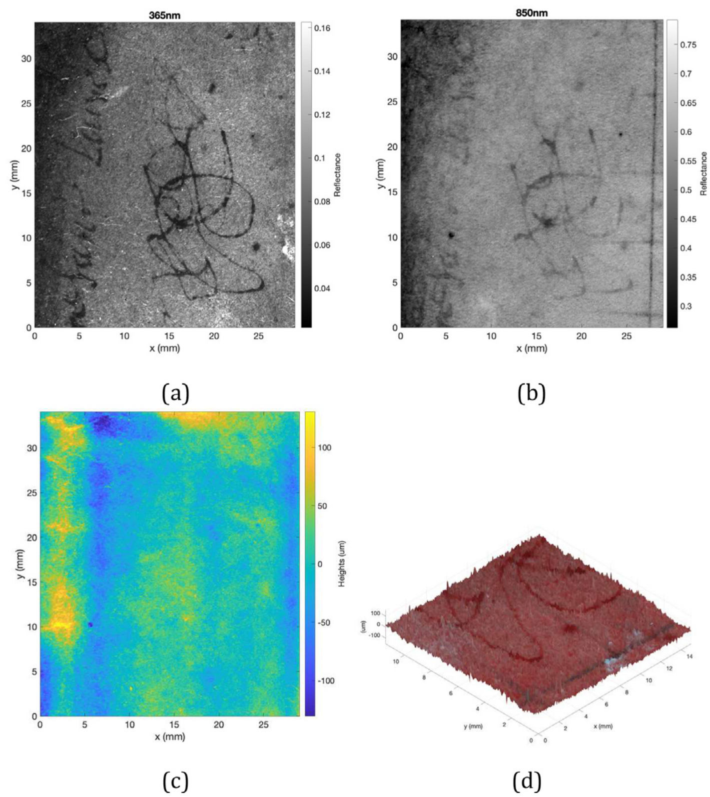


Fig. 5. Dual height-imaging dataset: by way of example (a) and (b) represent the scientific images in the UV (365 nm) and IR (850 nm) narrow bands registered with respect to the height map (c). (d) 3D texture plot of a ROI in false colors: 365 nm in the red channel, 385 nm in the green channel and 850 nm in the blue channel. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

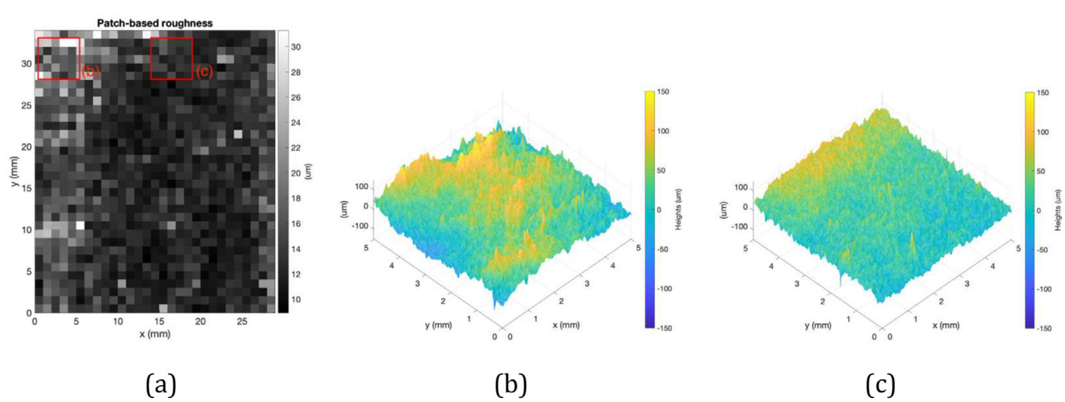


Fig. 6. (a) 1 mm^2 patch-based roughness inspection of the texture in the left scan. (b)-(c) Surface texture of two ROIs of 5 mm^2 in the border and in the middle.

so thin and the trace so flimsy to be undetectable by the micro-profilometer, highlighting the importance of registering the surface data with the multispectral stack. Fig. 5(d) shows, as example, a ROI of the surface map fused with the false-color composite image in the UV-IR bands using the 365 nm, 385 nm, and 850 nm channels. This composition allows to read UV-based information, e.g., the trace of a conservation or other unrelated compound, and IR-based information, e.g., the squaring lines.

In order to inspect the surface parameters, a multiscale analysis is performed as detailed in [19]. This approach allows to examine the surface in subregions enabling to detect the variation of the roughness features with the observation scale and the non-homogeneity of the texture. Fig. 6(a) shows the 1 mm^2 patch-based roughness of the whole left scan. As can be seen, there is a clear increase of the roughness toward the margin. Fig. 6(b) and (c) represent the three-dimensional surface topography of two representative ROIs of 5 mm^2 selected from the left scan, one at the extreme of the page and the other one in the upper middle part. These ROIs allow to appreciate the differences in the microsurface asperities as the surface analysis is performed near the edge.

The right scan offers the opportunity to analyse different type of writings, with inks and line types probably drawn with different tools. One of the most used techniques in the analysis of MSI is the use of the Principal Component Analysis (PCA) [4]. This processing generates a new set of uncorrelated images composed by a linear combination of the original images allowing to enhance the different features. The spatial registration of the multispectral dataset on the microsurface allows to map the pieces of information obtained through the PCA on the texture of the manuscript. Fig. 7 shows, as example, the first, the second, and the fifth principal component images mapped on the three RGB channels and superimposed to the surface. These components enhance the black, the red, and the yellow areas of the text. In addition, PCA reveals faint features such as the different responses of the black ink

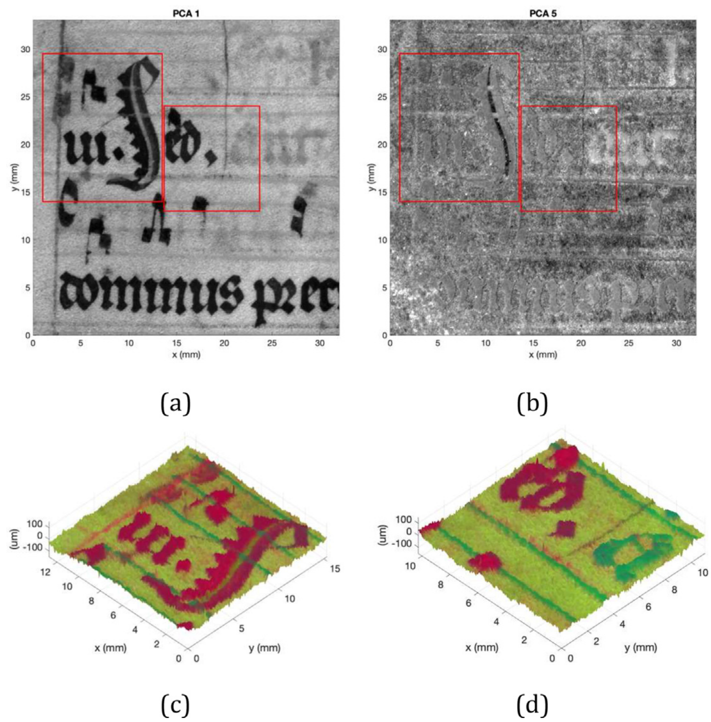


Fig. 7. (a) First principal component image. (b) Fifth principal component image, in which the yellow ink emerges. (c)-(d) Surface maps of the highlighted ROI with the first, the second, and the fifth principal component are mapped into RGB channels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

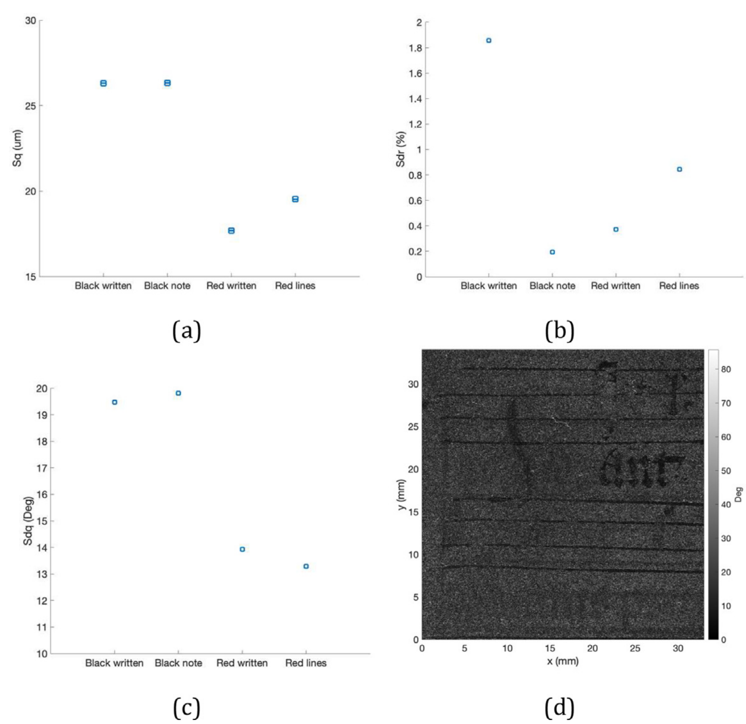


Fig. 8. Targeted analysis of the surface. (a) RMS roughness (Sq), (b) developed interfacial area ratio (Sdr), and (c) slope (Sdq). (d) Full field slope.

used for the letters and for the musical notes, possibly due to the different hands that wrote the manuscript with inks that differed in composition. It is interesting to note how it was possible to hypothesize that the inscription in the top left corner of the map in Fig. 7(d), which appears as a single shape, could be composed of a musical note and a letter linked together. Highlighting regions allow for multispectral-based surface segmentation. This approach is of particular interest in analysing the microsurface, observing the different degradation of text composed by different inks. For example, as can be noticed from Fig. 4(d) and the imaging, the red writing in the top right corner of the right scan is more deteriorated and exhibits a craquelure pattern.

The segmentation guided by the multispectral imaging allows to compute targeted roughness parameters (see Fig. 8), e.g., the ISO parameters RMS roughness *Sq*, the developed interfacial area ratio *Sdr*, and the slope *Sdq*, reported in Table 1, which have been shown effective in artwork surface metrology [18]. The surface data confirms the findings of the PCA in terms of different inks, also characterised by traces of different thickness as result of possible different density at the time of application. This highlights the strengths of combining the two MSI and microprofilometry techniques and how this data fusion can further guide point characterisation analyses.

4. Conclusions

The focus of this paper is the demonstration of the potential of surface analysis in book heritage applications. Given the fragility and the delicate essence of these objects, the integrity of the surface is a key aspect to monitor the conservation status. The main drawback of the microsurface exploration is the lack of reference point in the height map, which is particularly relevant in case of very flat objects such as texts. We solved this issue using a new method that allows to spatially register the microsurface with respect to the imaging stack by exploiting the raw intensity signal collected by the optical scanner microprofilometer. This enabled to combine the strengths of the two investigation techniques: MSI allows to discriminate different materials guiding the segmentation and the microprofilometry analysis.

The proof of concept presented on an ancient *folium* demonstrates the potential on a genuine artwork: the new dataset consisting of registered multispectral images and surface data allows to integrate the imaging analyses, such as PCA, and the additional microsurface information. This is of particular interest when the text is made of different inks or different diluition of the same ink as well as when the manuscript is subjected to non-homogeneous deterioration processes. Regarding the measurement, it is worth noting that the microprofilometer is based on a point-wise scanning technique that requires longer acquisition time compared to the single-shot full-field imaging method. Moreover, it is a prototype that requires advance instrumentation and expertise, e.g., for the selection of the most suitable lens-probe coupling and the resulting working range.

Overall, the integration of microprofilometry and multispectral imaging in full-field is new in the diagnostic protocol on ancient manuscripts, and it is expected to advance the field.

CRediT authorship contribution statement

S. Mazzocato: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **D. Cimino:** Writing – review & editing. **C. Daffara:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Acknowledgements

The authors thank conservator Valerio Capra who made the ancient manuscript available, Giacomo Marchioro who acquired the multispectral images, and BBZ srl for 3D printing the optical fiber support.

References

[1] Z. Sebestyén, Z. Czégény, E. Badea, C. Carsote, C. Şendrea, E. Barta-Rajnai, J. Bozi, L. Miu, E. Jakab, Thermal characterization of new, artificially aged and historical leather and parchment, J. Anal. Appl. Pyrolysis 115 (2015) 419–427, doi:10.1016/j.jaap.2015.08.022.

[2] C. Chahine, Changes in hydrothermal stability of leather and parchment with deterioration: a DSC study, Thermochim. Acta 365 (1–2) (2000) 101–110, doi:10.1016/s0040-6031(00)00617-1.

[3] E. Badea, L. Miu, P. Budrugeac, M. Giurginca, A. Mašić, N. Badea, G.D. Gatta, Study of deterioration of historical parchments by various thermal analysis techniques complemented by SEM, FTIR, UV-vis-NIR and unilateral NMR investigations, J. Therm. Anal. Calorim. 91 (1) (2008) 17–27, doi:10.1007/s10973-007-8513-x.

[4] C. Jones, C. Duffy, A. Gibson, M. Terras, Understanding multispectral imaging of cultural heritage: determining best practice in MSI analysis of historical artefacts, J. Cult. Herit. 45 (2020) 339–350, doi:10.1016/j.culher.2020.03.004.

[5] R. Qureshi, M. Uzair, K. Khurshid, H. Yan, Hyperspectral document image processing: applications, challenges and future prospects, Pattern Recognit. 90 (2019) 12–22, doi:10.1016/j.patcog.2019.01.026.

[6] K.T. Knox, Enhancement of overwritten text in the archimedes palimpsest, in: D.G. Stork, J. Coddington (Eds.), Computer Image Analysis in the Study of Art, vol. 6810, International Society for Optics and Photonics, SPIE, 2008, p. 681004, doi:10.1117/12.766679.

[7] S. Joo Kim, F. Deng, M.S. Brown, Visual enhancement of old documents with hyperspectral imaging, Pattern Recognit. 44 (7) (2011) 1461–1469, doi:10.1016/j.patcog.2010.12.019.

[8] R.L. Easton, W.A. Christens-Barry, K.T. Knox, Spectral image processing and analysis of the archimedes palimpsest, in: 2011 19th European Signal Processing Conference, 2011, pp. 1440–1444.

[9] A. Tonazzini, E. Salerno, Z.A. Abdel-Salam, M.A. Harith, L. Marras, A. Botto, B. Campanella, S. Legnaioli, S. Pagnotta, F. Poggialini, V. Palleschi, Analytical and mathematical methods for revealing hidden details in ancient manuscripts and paintings: a review, J. Adv. Res. 17 (2019) 31–42, doi:10.1016/j.jare.2019.01.003.

[10] D. Cimino, G. Marchioro, P. De Paolis, C. Daffara, Evaluating the integration of thermal quasi-reflectography in manuscript imaging diagnostic protocols to improve non-invasive materials investigation, J. Cult. Herit. 62 (2023) 72–77, doi:10.1016/j.culher.2023.04.009.

[11] G. Bianco, F. Bruno, A. Tonazzini, E. Salerno, P. Savino, B. Zitova, F. Sroubek, E. Console, A framework for virtual restoration of ancient documents by combination of multispectral and 3D imaging, in: Eurographics Italian Chapter Conference 2010, 2010, doi:10.2312/LocalChapterEvents/ItalChap/ItalianChapConf2010/001-007.

[12] A. Facchini, C. Malara, G. Bazzani, P.L. Cavallotti, Ancient parchment examination by surface investigation methods, J. Colloid Interface Sci. 231 (2) (2000) 213–220, doi:10.1006/jcis.2000.7138.

[13] A. Bartoletti, M. Odlyha, S. Hudziak, K.M. Axelsson, J. de Groot, L. Bozec, Visibilia ex invisibilibus: seeing at the nanoscale for improved preservation of parchment, Insight - Non-Destr. Test. Cond. Monit. 59 (5) (2017) 265–272, doi:10.1784/insi.2017.59.5.265.

[14] A. Casoli, P. Cremonesi, C. Isca, R. Groppetti, S. Pini, N. Senin, Evaluation of the effect of cleaning on the morphological properties of ancient paper surface, Cellulose 20 (2013) 2027–2043, doi:10.1007/s10570-013-9975-6.

[15] T.R. Vijaya Lakshmi, P.N. Sastry, T.V. Rajinikanth, A novel 3D approach to recognize Telugu palm leaf text, Eng. Sci. Technol. Int. J. 20 (1) (2017) 143–150, doi:10.1016/j.jestch.2016.06.006.

[16] A. Papanikolaou, D. Dzik-Kruszelnicka, M. Kujawinska, Spatio-temporal monitoring of humidity induced 3D displacements and strains in mounted and unmounted parchments, Heritage Sci. 10 (15) (2022), doi:10.1186/s40494-022-00648-y.

[17] G.S. Spagnolo, C. Simonetti, L. Cozzella, Superposed strokes analysis by conoscopic holography as an aid for a handwriting expert, J. Opt. A: Pure Appl. Opt. 6 (9) (2004) 869–874, doi:10.1088/1464-4258/6/9/009.

[18] C. Daffara, S. Mazzocato, Surface metrology based on scanning conoscopic holography for in situ and in-process monitoring of microtexture in paintings, Sensors 22 (17) (2022), doi:10.3390/s22176637.

[19] C. Daffara, S. Mazzocato, G. Marchioro, 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 (4) (2022) 430, doi:10.1140/epjp/s13360-022-02605-x.

[20] S. Mazzocato, C. Daffara, A method for spatially registered microprofilometry combining intensity-height datasets from interferometric sensors, Sensors 23 (8) (2023) 4144, doi:10.3390/s23084144.

[21] MATLAB, Version 9.13.0.2105380 (R2022b), The MathWorks Inc., Natick, Massachusetts, 2022.

[22] C. Daffara, S. Mazzocato, G. Marchioro, Optical surface metrology for heritage science: proof of concept and critical-constructive discussion, Proc. SPIE 12620 (2023) 126200C, doi:10.1117/12.2675055.