Visualising macroscopic degradation of parchment and writing via multispectral images

In: Driscoll, M.J. (ed.), “Care and conservation of manuscripts 15: proceedings of the fifteenth international seminar held at the University of Copenhagen 2nd- 4th April 2014.” Copenhagen: Museum Tusculanum Press.

Alejandro Giacometti, Department of Medical Physics & Bioengineering,
UCL Centre for Digital Humanities, University College London, London

Alberto Campagnolo, Ligatus Research Centre, CCW Graduate School,
University of the Arts London, London

Lindsay MacDonald, Photogrammetry, 3D Imaging & Metrology Research Centre,
University College London, London

Simon Mahony, UCL Centre for Digital Humanities, Department of Information Studies,
University College London, London

Stuart Robson, Photogrammetry, 3D Imaging & Metrology Research Centre,
University College London, London

Tim Weyrich, Department of Computer Science, UCL Centre for Digital Humanities,
University College London, London

Melissa Terras, UCL Centre for Digital Humanities, Department of Information Studies,
University College London, London

Adam Gibson, Department of Medical Physics & Bioengineering,
University College London, London

Digital imaging technology can now produce detailed and trustworthy surrogates of historical documents.[1] Leveraged by technological improvements in imaging and image processing, humanities scholars have been able to image, analyse, and recover more information from historical documents than was previously possible.[2,3,4] Multispectral imaging has been utilised to examine the characteristics of documents by providing additional information about their physical properties and condition.[5,6,7] However, current digitisation efforts have concentrated on recording documents in their current state. In this project we used multispectral imaging to record the process of macroscopic document degradation by imaging a parchment document before and after a series of degradation processes. This project is part of a larger effort to investigate the methodologies for acquiring and processing multispectral images of damaged cultural heritage documents.[8,9]

The manuscript

A deaccessioned eighteenth-century manuscript was obtained from the London Metropolitan Archives. It had been determined to hold no historical value, and was thus handed over to our lab for experimentation. The manuscript is composed of two large leaves (Fig. 1), which were folded in thirds both horizontally and vertically. It is written in iron gall ink on prepared animal skin – parchment – and measures approximately 70 × 70 cm. Both leaves have red margin guidelines and a blue seal has been glued outside the left margin. The outer leaf contains a large stamp on the top left corner and a fold trapping the inner leaf with red wax. Both leaves have writing on the recto covering most of the area of the leaf enclosed by the red margin. The outer leaf has a written section on its verso, which details the date, and the contents of the document. The recto of the manuscript corresponds with the flesh side of the parchment, the verso with the hair side. It is dated to 11th of August 1753. It is an indenture, or land contract, between a Mr John Sherman and a Mr Christ Gardiner.

Fig. 1. Iron gall ink on parchment manuscript. Dated 1753. Deaccessioned from the London Metropolitan Archives.

Twenty-three 8 × 8 cm flat square sections were cut from the parchment as samples for the experiment. Each sample contains written text. Fig. 1 shows the location of the samples cut from both leaves of the document. Each sample was selected from a flat area of the manuscript, where the writing covers the surface of the recto, and the verso is empty and without blemishes. Folds and marks of any kind were avoided. There were three exceptions: two of the samples were cut so as to contain writing on both the recto and verso, and one sample is cut from a folded area. The fold sample and one of the samples with writing on both sides were kept as controls. The additional sample with writing on both sides was specially selected for treatment with oil, as it was expected that oil would make the sample translucent, visually blending the writing on both sides of the sample.

Degradation procedures

Apart from some signs of wear and tear, especially aligned with the folds, the document was in overall good condition. A series of treatments were applied to damage the 20 samples; three additional samples were left untreated and kept intact as controls. We selected a series of damage agents, which include both physical and chemical agents, to mimic the kinds of damage parchment documents can be expected to incur during their lives, from technological mistakes during production, to improper use, unsuitable storage condition, disasters, and natural ageing. Depending on the agent causing the degradation, damages can be grouped into three categories: mechanical, thermochemical & humidity or due to extraneous physical or chemical agents.[10]

These damage agents were selected so as to affect the properties of the parchment, but also the legibility of text in various ways, for example, shrinking or otherwise deforming the parchment, obscuring or effacing the writing via physical, chemical or biological reactions.[11]

Table 1 details the chosen methods of degradation agents (in small capitals), the reason for the damage and the circumstances in which it might have occurred in real life. In the table are also highlighted the kinds of degradation that naturally occurred to the manuscript during our experiments; these are identified by the keyword *Controls*. Preliminary testing was performed to determine the parameters and viability of each treatment.[12] Samples were kept in separate plastic airtight containers when not in use.

Table 1. Summary of different types of degradation, giving the reason for the degradation, the circumstances in which it might occur and the type of degradation.

Degradation Reason		*Circumstances*	*Mechanical*	*Chemical, biological or environmental damage*	*Damage by extraneous substances*
Technological mistakes	During manufacture	lime solution, acidity, finishing	SCRAPING	HYDROCHLORIC ACID, CALCIUM HYDROXIDE	OIL
	During writing	ink acidity		SULPHURIC ACID	
	During binding	unsympathetic binding	MECHANICAL DAMAGE		
Storage	Environmental changes	temperature, humidity		HEAT, DESICCANT, MOULD	
	Exposure to light	visible light, UV		UV LIGHT, CONTROLS	
	Pollutants, dirt	chemical reactions		SMOKE, SULPHURIC ACID, CONTROLS	
	Natural disasters	fire, smoke, water		HEAT, SMOKE, WATER	
	Biodegradation	micro-organisms, insects, rodents		MOULD	
	Mechanical destruction	rubbing, folding	MECHANICAL DAMAGE		
Use	Erasures, changes to text	corrections, re-usage	SCRAPING		IRON GALL INK
	Mishandling, misuse		MECHANICAL DAMAGE, SCRUNCHING		
	Accidents	spillage		BLOOD, RED WINE,	BLOOD, OIL,

				Black Tea, Iron Gall Ink, Water	Red Wine, Black Tea, Aniline Dye, Iron Gall Ink, Indian ink
	Repairs	historical, conservation treatments		Water, Sodium Hypochlorite	
	Rebinding	unsympathetic binding	Mechanical Damage		
	Palaeographical and conservation experiments	palimpsest text recovery, bleaching		Hydrochloric Acid	Oil
	Reformatting, digitisation		Mechanical Damage	UV Light	
Natural ageing				Controls	

Multispectral imaging

The visible spectrum – light that is visible to humans – is defined by wavelengths from approximately 400 nm to 700 nm. Light with wavelengths longer than 700 nm is referred to as infrared; ultraviolet refers to light with wavelengths shorter than 400 nm.[13] A multispectral image is collected by measuring a series of wavelengths over a broad range of the visible and near infrared spectrum (Fig. 2). In a multispectral image, each pixel represents a measurement gathered from an object, and this records information that enables the investigation and identification of the materials that compose that object[14].

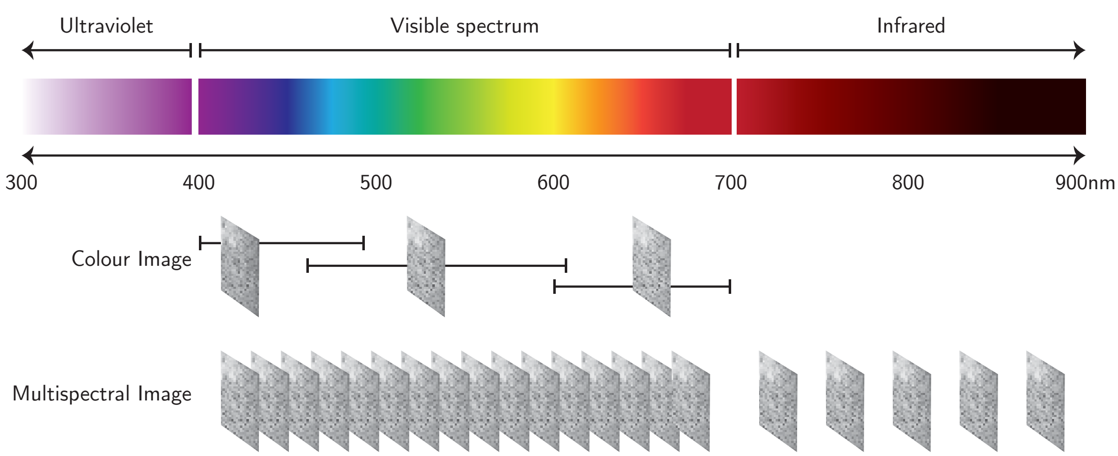

Fig. 2. Multispectral images are captured in a similar process as colour images. A colour image is a combination of three separate images captured at selected ranges of the visible spectrum representing blue, red and green tones. A multispectral image is captured is a combination of a series of images captured at discrete narrow ranges of the light spectrum.

Therefore, multispectral images provide information about physical characteristics of the samples, and may be used to identify materials present in the ink, parchment or even extraneous substances. In combination, the images of a sample before and after the degrading agent has been applied can also offer clues to how the agent has transformed those identified materials. This information may further provide insights into identifying damage in other documents. The use of the multispectral imaging within the cultural heritage sector has seen early success at recovering writing from high profile documents such as the Archimedes Palimpsest,[15,16] the Dead Sea Scrolls,[17,18] letters from the Hudson Bay Archives[19] and palimpsests from St Catherine's Monastery in Egypt.[20]

Using a multispectral imaging system, each of the treated samples has been photographed before and after treatment to record the effect of the treatments on both the writing and the parchment. A series of 21 bandpass filters centred at regular intervals of the visible and near-infrared spectrum were used in combination with reflective and transmissive lighting. Each bandpass filter blocks all light except for a short range around a specific wavelength. Each pixel of the image captured by the camera is then a measurement of light as it interacted with the materials present in the parchment at one coordinate. The combination of those images, photographed under each filter then provides a map of spectral responses for each pixel. The samples were photographed using a colour consumer camera (digital SLR Nikon D200) and a wide spectral range monochrome camera (Kodak Megaplus 1.6i). Fig. 3 details a single feature in a sample, and the variation in intensity and contrast of the writing and ink across the imaged wavelengths. It can be observed how, initially, the ink gains contrast slightly, with a darker background in the shorter wavelengths. Around the longer wavelengths in the visible spectrum and into the near-infrared contrast suddenly drops quite significantly, rendering the contrast in the 900 nm image almost null.

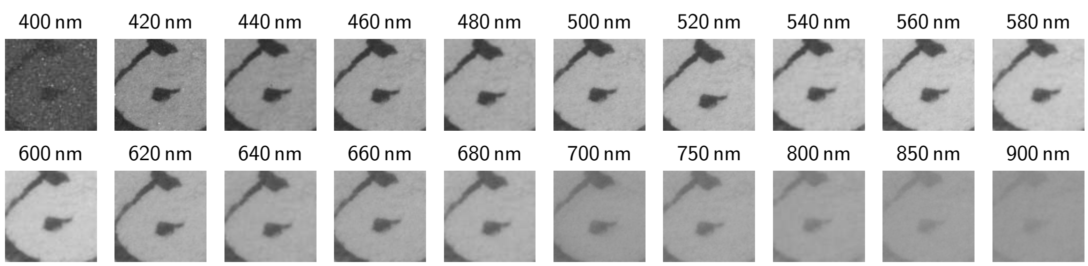

Fig. 3. Multispectral Detail of a single feature. Reflective Illumination. Monochrome Camera.

The effect of each treatment on the writing and parchment varied significantly. Some treatments, like mechanical damage, UV light, desiccant, water and calcium hydroxide, had little effect on the writing or the document's integrity. Other treatments, like the inks, dye and blood almost completely obscured the writing making it very difficult to read. Some treatments, such as oil, tea, wine and smoke, acted to reduce the contrast between the parchment and the writing. A few treatments changed the structure of the sample considerably, rendering it fragile or even brittle; these include mould, heat and sodium hypochlorite.

We describe three examples from the twenty treatments below. These examples illustrate the different ways in which the writing was affected: one where the writing has been scraped, a second one where the writing remains but has been obscured by a stain, and a final one where the writing has been bleached. A full report for all of the samples is available.[21]

Example 1. Scraping

Forcibly removing the surface layer and the visible writing from the parchment with pumice stone was a commonly employed method to re-use parchment.[22] Recovering faint writing is a similar, but separate problem with historical documents.[23] The procedure sometimes involved softening the parchment using a mixture of cheese, milk and lime before proceeding to scrape the writing using a knife or razor.[24]

Scraping has rendered the affected areas illegible to the naked eye (Fig. 4). There are traces on the middle third of the sample, where the scraping was lighter. The bottom third has very few marks where the writing used to be. On the top third, where a single word was removed, there is a darker mark on the parchment, but no traces of the word can be seen.

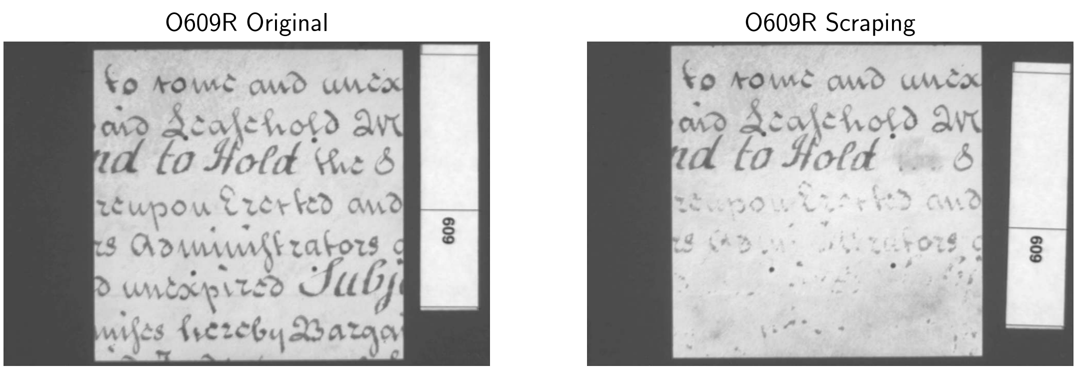

Fig. 4. Sample before and after scraping. Average of wavelengths captured using the monochromatic camera in reflective lighting.

The lower area of the sample was scraped the most, making the parchment visibly thinner. The treated sample shows the same lower area darker, as the black card underneath the sample shows through because light is able to travel through the thinner parchment. There is also a darker area where the single word was scraped off.

Example 2. Blood

Bloodstains are not uncommon in historical documents.[25] Moreover, blood looks similar to iron gall ink as haemoglobin is rich in iron, which should contribute to the difficulty of separating the ink in the writing from bloodstains. However, in other contexts, such as criminology, multispectral imaging has been found to be of assistance when dating blood stains at crime scenes.[26]

On the sample, the blood treatment has obscured the writing. The bloodstains are of a dark brownish colour. As it can be observed in Fig. 5, the lack of contrast between the stained parchment and the ink renders the writing almost illegible, although visible.

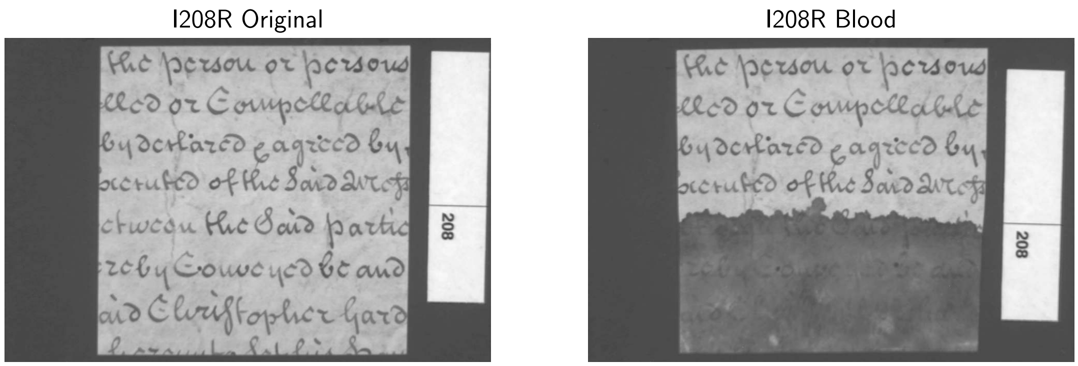

Fig. 5. Sample before and after damage by blood. Average of wavelengths captured using the monochromatic camera in reflective lighting.

Example 3. Sodium hypochlorite

Sodium hypochlorite is a strong alkaline substance and a common bleaching agent. Reports of experiments with both paper and parchment describe the bleaching effects of both the parchment turning pink and the iron gall ink fading.[27] There are also anecdotes of unscrupulous grey market bleaching of parchment during cleaning.

The writing in the sodium hypochlorite treated sample has become very faint (Fig. 6). Both the parchment and the writing have become lighter. The areas where the writing is stronger seem to be where there are stronger ink marks, suggesting that the ink would have penetrated further into the structure of the parchment. During the application of the treatment, the parchment started losing structural integrity and some small particles separated from the sample. The treatment was stopped earlier than planned because of this, as the sample needed to be preserved for imaging purposes. After drying, the sample became stable again. However, it remained in a quite fragile state; it feels lighter to the touch, it is more transparent, smoother and more flexible than before treatment.

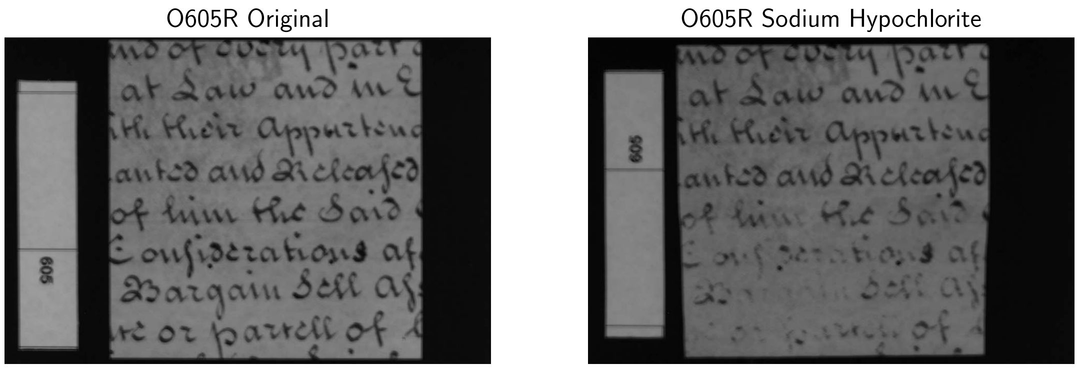

Fig. 6. Sample before and after treatment with sodium hypochlorite. Average of wavelengths captured using the monochromatic camera in reflective lighting.

Degradation effects

The degradation of the samples varies significantly, from partially obscuring the writing, to completely covering it, changing the geometry of the sample, or even changing the physical properties of the sample. Fig. 7 shows the spectral variation of a random selection of pixels from the examples above, before and after treatment. These plots give an idea of the severity of the change that the samples have experienced and the kind of data that multispectral imaging can deliver. The three spectral plots of the untreated samples show two distinct groups of concentrated pixels, a larger group with higher intensity which corresponds to the parchment and a second smaller with lower intensity which corresponds to the writing. The two groups converge at the longer wavelengths, which confirms the loss in contrast observed in fig. 3. In the plots of the treated samples, these groups have been altered in different ways. The writing group from the scraped sample is now indistinguishable. A much larger, dark group can be observed in the blood treated sample. Finally, the effect in the bleached sample is less severe, although the group corresponding to the writing does seem to be diminished relative to the untreated plot.

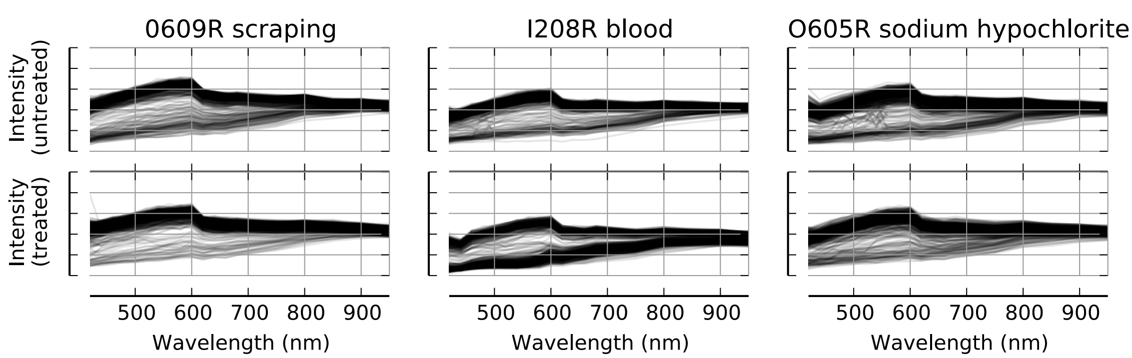

Fig. 7. Sampling of pixel intensity across wavelength for the three examples before and after treatment is applied.

In some samples the writing has been rendered illegible by the treatment. This is the case with hydrochloric acid, iron gall ink, India ink, mould, aniline dye, and to a lesser extent, blood. In some of these cases, the multispectral data supplied may be able to be used to recover some of the writing. However, samples like the one treated with mould have suffered significant damage, not only affecting the writing, but also the condition of the parchment itself. Similarly, the sample treated with heat has shrunk, hardened and become darker. In this case, however, the writing is still plainly visible to the naked eye.

In other samples, the degradation has not been significant. The writing in these samples is still legible after the treatment is applied, even if some interference from the treatment is present. Such is the case with staining due to red wine, tea, soot from smoke, and oil. Another group has suffered very minimally, the writing being unaffected or only slightly so. The images from the samples look very similar before and after the treatments were applied.

In Fig. 8, small images of all the treated samples are placed alongside the spectral plots. As in Fig. 7, in the spectral plot for the untreated samples, two clearly defined groups of measurements can be distinguished, which correspond to the pixels describing parchment and ink. The spectral variation of the samples confirms the macroscopic visual analysis. Samples which have suffered from the most severe degradation also display changes in their spectral responses. Dark concentrated groups of pixels across wavelength can be observed in the samples affected by stains. The severe effects of mould show an almost flat spectral response that is constant for all pixels, indicating the certain destruction of the writing. In the sample treated with oil, it is the parchment which has been affected, rendering darker, less cohesive measurements with a larger spread in intensity. Finally, almost identical spectral responses can be observed from the samples in which the treatment has had less severe consequences, such as desiccant, scrunching, mechanical damage and water.

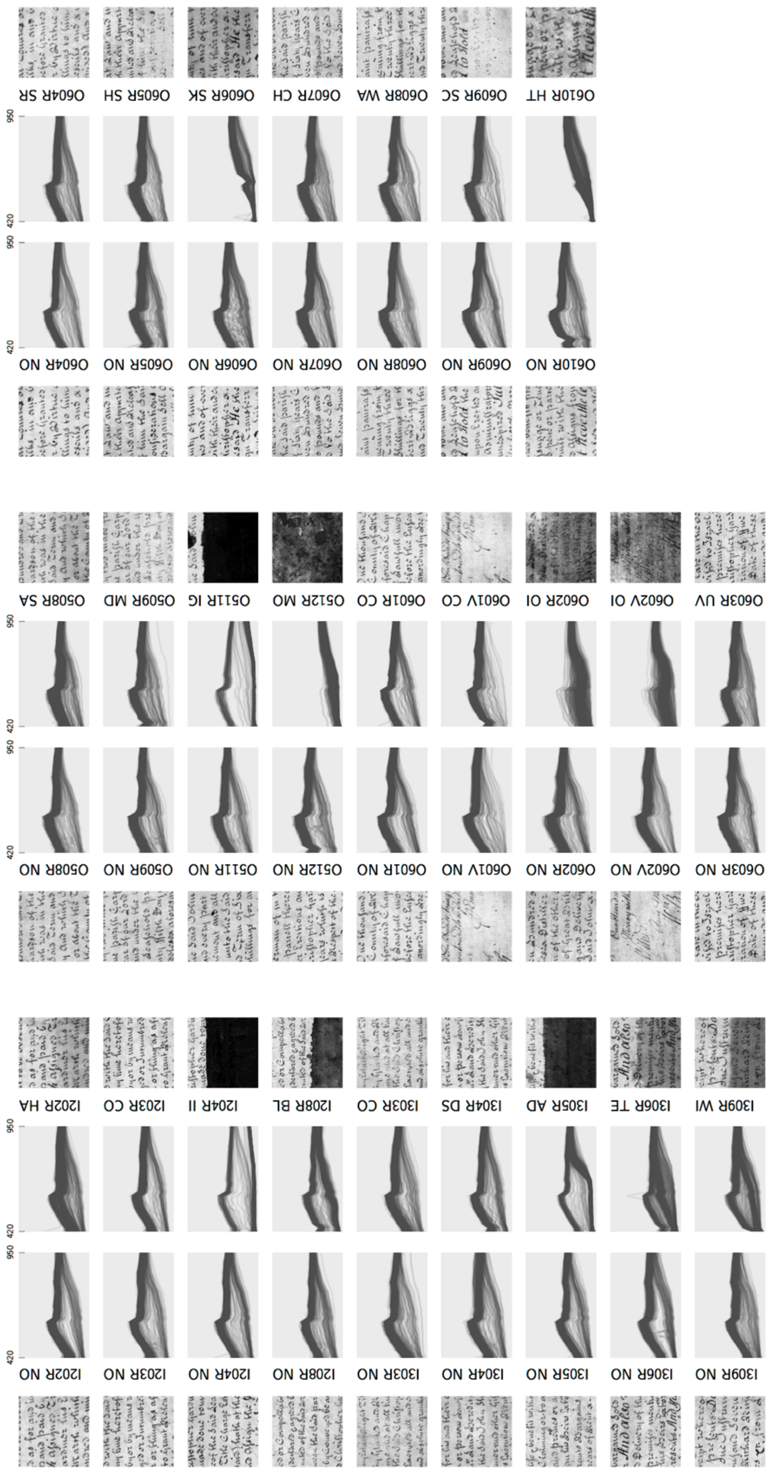

Fig. 8. Sampling of pixel intensity across wavelength on all samples before and after treatment is applied.[28] For each sample an image before treatment is shown, followed by a spectral plot of the sample before treatment, a spectral plot of the sample after treatment, and finally an image of the treated sample. As in Fig. 7, the variation on the spectral plots provides confirmation of the visible effects of the treatment on each sample.

Conclusions & related work

The data from our experiments forms a set of multispectral images showing both the initial and degraded state of a manuscript – approximately 3000 images of samples and 300 calibration images, white-corrected, registered and analysis images, along with data manipulation methods, image processing procedures. Additionally, we documented the treatments and the procedures that were followed. We believe that these can become a valuable resource for both conservation research and libraries and archives undergoing digitisation efforts.

Our dataset and sample set provide direct advantages to the Conservation community as they can offer a classification of degradation agents on parchment and a possible way of identifying the rate and type of damage by visual analysis. Furthermore, our project formalises a methodology to document damage on parchment; it provides a template for similar investigations with other cultural heritage objects.

Concurrent work with our dataset includes the quantitative evaluation and analysis of the effectiveness of common image processing algorithms used to digitally restore images of degraded writing. Multispectral images of the samples before the damage provide a ground truth, which can be compared with digital estimates prepared using the images of the degraded samples.[29]

This is a collaborative project undertaken by a group of researchers in a diverse set of fields, including, Image Science, Conservation, Medical Physics, Digital Humanities.

[1] Terras, M. 'Image to Interpretation: An Intelligent System to Aid Historians in Reading the Vindolanda Texts' (Oxford University Press, Oxford, UK, Dec. 2006).

[2] Salerno, E., Tonazzini, A. & Bedini, L. 'Digital image analysis to enhance underwritten text in the Archimedes palimpsest'. *International Journal on Document Analysis and Recognition* (2007) Vol. 9, No. 2-4, pp. 79-97.

[3] Tanner, S. & Bearman, G. 'Digitizing the Dead Sea Scrolls'. *Archiving 2009* (Arlington, VA, USA 2009). The Society for Imaging Science and Technology, pp. 119-123.

[4] Chabries, D. M., Booras, S. W. & Bearman, G. 'Imaging the past: A recent applications of multispectral imaging technology to deciphering manuscripts'. *Antiquity* (2003). Vol. 77, No. 296, pp. 359-372.

[5] Bearman, G. & Spiro, S. I. 'Archaeological Applications of Advanced Imaging Techniques'. *The Biblical Archaeologist* (Mar. 1996). Vol. 59, No. 1, pp. 56-66.

[6] Attas, E. M. 'Enhancement of Document Legibility Using Spectroscopic Imaging'. *Archivaria* (Mar. 2004). Vol. 57, pp. 121-146.

[7] Knox, K. T. 'Enhancement of overwritten text in the Archimedes Palimpsest'. In *Proc. SPIE 6810, Computer Image Analysis in the Study of Art* (2008).

[8] Giacometti, A., Campagnolo, A., MacDonald, L., Mahony, S., Terras, M., Robson, S., Weyrich, T. & Gibson, A. 'Cultural Heritage Destruction: Documenting Parchment Degradation via Multispectral Imaging'. In *Electronic Visualisation and the Arts (EVA 2012)* (British Computing Society, London, UK, July 2012). pp. 301-308

[9] MacDonald, L. W., A. Giacometti, A. Campagnolo, S. Robson, T. Weyrich, M. Terras and A. Gibson. 'Multispectral Imaging of Degraded Parchment'. *Computational Color Imaging, 4th International Workshop, CCIW 2013, Chiba, Japan, March 3-5, 2013*. Proceedings. Ed. by S. Tominaga, R. Schettini and A. Trémeau. Vol. 7786. Lecture Notes in Computer Science. Chiba, Japan: Springer Berlin Heidelberg. (2013)

[10] Vnouček, J. 'Typology of the Damage of the Parchment in Manuscripts of the Codex Form'. In *Improved damage assessment of parchment (IDAP): assessment, data collection and sharing of knowledge*. (ed Larsen, R.) 1st ed., pp. 27-30 (European Commission, Directorate- General for Environment, 2007).

[11] Giacometti, A. 'Evaluating Multispectral Imaging Processing Methdologies for Analysing Cultural Heritage Documents'. (PhD Thesis, University College London, 2013)

[12] Giacometti et al, 'Cultural Heritage Destruction', pp. 301-308

[13] Peatross, J. & Ware, M. 'Physics of Light and Optics' 2013th ed. (2013).

[14] Vane, G. & Goetz, A. F. 'Terrestrial imaging spectroscopy'. *Remote Sensing of Environment* (Feb. 1988). Vol. 24, No. 1, pp. 1-29.

[15] Salerno, Tonazzini & Bedinin, Digital Image, pp. 79-97

[16] Netz, R. & Noel, W. 'The Archimedes Codex: How a Medieval Prayer Book Is Revealing the True Genius of Antiquity's Greatest Scientist' 1St Edition (Da Capo Press, Oct. 2007).

[17] Chabries, Booras & Bearman, 'Imaging', pp. 359-372.

[18] Tanner &Bearman, 'Digitizing', pp. 119-123.

[19] Goltz, D. M., Cloutis, E., Norman, L. & Attas, E. M. 'Enhancement of Faint Text Using Visible (420-720nm) Multispectral Imaging'. *Restaurator* (Jan. 2007). Vol. 28, No. 1, pp. 11-28.

[20] Easton Jr., R. L., K. T. Knox, W. A. Christens-Barry, K. Boydston, M. B. Toth, D. Emery and W. Noel. 'Standardized system for multispectral imaging of palimpsests'. *Proc. SPIE 7531, Computer Vision and Image Analysis of Art*. (2010) 75310D.111

[21] Giacometti, 'Evaluating'

[22] Netz & Noel, 'Archimedes'.

[23] Goltz et al., 'Enhancement', pp. 11-28.

[24] Diringer, D. 'The Book Before Printing: Ancient, Medieval, and Oriental' (Courier Dover Publications, Mineola, NY, USA, 1953).

[25] Wechsler, T. 'The Origin of the So Called Dead Sea Scrolls.' *The Jewish Quarterly Review* (Oct. 1952). Vol. 43, No. 2, pp. 121-139.

[26] Edelman, G., van Leeuwen, T. G. & Aalders, M. C. 'Hyperspectral imaging for the age estimation of blood stains at the crime scene'. *Forensic Science International* (Nov. 2012). Vol. 223, No. 1, pp. 72-77.

[27] Smith, T. 'An Evaluation of Historical Bleaching with Chlorine Dioxide Gas, Sodium Hypochlorite, and Chloramine-T at the Fogg Art Museum'. *Restaurator* (2012). Vol. 33, No. 3-4, pp. 249-273.

[28] For convenience purposes, treatments in sample titles are abbreviated with two letter codes: AD, Aniline Dye; BL, Blood; CH, Calcium Hydroxide; CO, Control; DS, Desiccant; HA, Hydrochloric Acid; HT, Heat; IG, Iron Gall Ink; II, India Ink; MD, Mechanical Damage; MO, Mold; NO, No treatment (images of samples before any treatment was applied); OI, Oil; SA, Sulphuric Acid; SC, Scraping; SH, Sodium Hypochlorite; SK, Smoke; SR, Scrunching; TE, Tea; UV, Ultraviolet light; WA, Water 7.0 pH; WI, Red Wine.

[29] Giacometti, 'Evaluating'