Colour Analysis of Degraded Parchment

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ABSTRACT

Multispectral imaging was employed to collect data on the degradation of an 18th century parchment by a series of physical and chemical treatments. Each sample was photographed before and after treatment by a monochrome digital camera with 21 narrow-band filters. A template-matching technique was used to detect the circular holes in each sample and a four-point projective transform to register the 21 images. Colour accuracy was verified by comparison of reconstructed spectra with measurements by spectrophotometer.

1. INTRODUCTION

Large collections of parchment documents exist in public and private libraries, archives, and museums in varying degrees of preservation. Parchment is prepared from an animal skin that has been wetted, immersed in lime water, dehaired, scraped, then left to dry under tension on a wooden frame. The stretching has the effect of reorganising the collagen fibre network into a laminate structure. The resulting material is a fairly stiff sheet which is durable and can last for centuries, provided it is kept cool and dry (Clarkson, 1992).

In this project, we investigated the processes of controlled document degradation using multispectral imaging. We obtained an 18th century manuscript de-accessioned from the London Metropolitan Archives (Fig. 1). Although in good physical condition, this manuscript was deemed to hold no historical value, and it was kindly donated for experimentation. It comprised two large sheets of prepared animal skin, i.e. parchment, written in iron gall ink and highlighted in red ink. Each sheet measured approximately 70×70 cm (Fig. 1), and the two had been tightly folded together for storage. The document was an indenture (contract) between Mr John Sherman and Mr Christ Gardiner dated 11th August 1753.

Figure 1: Detail of C18th parchment.

Twenty-three square sections of 8×8 cm were cut from the original manuscript, with each section containing written text. Each sample was exposed to a different external deteriorating agent to produce a controlled degradation, including mechanical damage, heat, humidity, abrasion and a variety of substances with different chemical properties, such as acid, alkaline, bleach, red wine, tea, human blood and mould. These affected the appearance and condition of the samples in different ways, typical of the actual damage suffered by parchment in real archives. Preliminary tests proved the viability of the procedures for degrading the samples and enabled parameters to be established for each treatment process (Giacometti *et al*, 2012).

2. MULTISPECTRAL IMAGE CAPTURE

Multispectral imaging can be used to discriminate between reflectance spectra, and hence to identify and separate different types of inks in a single document, showing whether the document has been edited. The carbon black ink of antiquity consisted of graphite or soot particles suspended in an organic binder and applied with a stylus. Such inks do not penetrate the parchment but rest on top, with particles adhering to the micro-structure of the surface. Iron gall ink, also known as gallo-tannin ink, was introduced around the third century AD, prepared with organic material that penetrates more deeply into the substrate and reacts, staining it black. Chabries *et al* (2003) noted that parchment reflectance increases at longer wavelengths, resulting in greater contrast of text in infrared images.

Each of our parchment samples was imaged before and after treatment through a series of bandpass filters, illuminated by four tungsten-halogen lamps on a photographic copystand. The Kodak Megaplus 1.6i camera with Nikkor 50 mm f/2 lens captured monochrome images of 1536x1024 pixels in both the visible and near-infrared spectrum over the range 400–1100 nm. A set of 21 bandpass optical interference filters was used, spaced at 20nm intervals across the visible spectrum and 50nm in the infrared. The spectral transmittance of each filter was measured with an Ocean Optics HR2000+ spectrometer.

Because parchment is prone to curl, a 3 mm glass plate with anti-reflective coating was placed over the sample to hold it flat on the baseboard. In total 23x21x2 = 966 images were captured by the Kodak camera for all parchment samples before and after treatment. Four circular holes of diameter 1 mm were drilled in each sample at approximately one third and two thirds of the width and height. These holes are apparent in each image and remained as persistent features after the samples were degraded, both as reference points for registration of the multispectral image channels and for comparison of image sets of the samples before and after treatment.

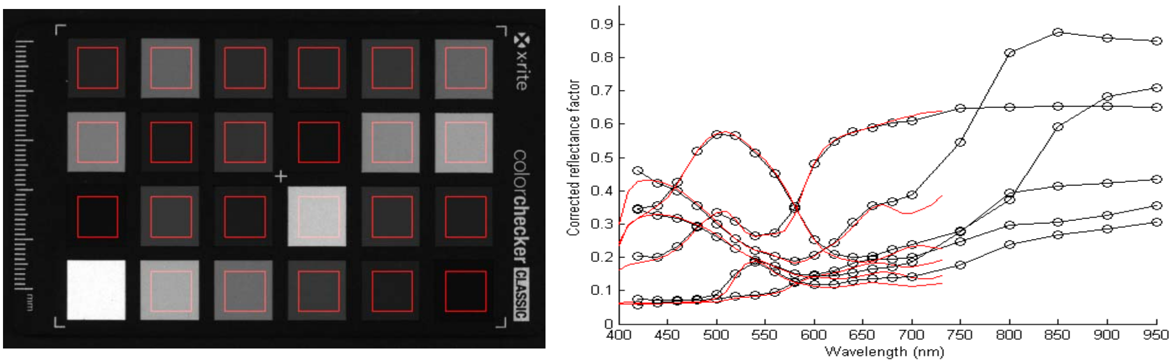

Figure 2: (left) 580nm image of MiniMacbeth target with sampling boxes; (right) reflectance factor vs wavelength for camera (black lines with circles) and spectrophotometer (red lines) for top row.

To check the accuracy of reconstruction of reflectance spectra from the multispectral image sets, a MiniMacbeth target was measured with an X-rite i1Pro spectrophotometer at 10nm intervals from 380 to 730 nm. The results were in good correspondence with the corrected camera responses for all four rows of the MiniMacbeth target (Fig. 2). The camera values at 400 nm were not reliable because the very low power of the lamp in this waveband required excessively long integration times for image capture, with consequent low signal-to-noise ratio. The CIE $L^*a^*b^*$ values were calculated for each reflectance spectrum, using the CIE 2° standard observer and illuminant D65, and the mean colour difference over the 24 patches was $\Delta E^*_{ab} = 3.4$. The maximum error was 6.5 for the fourth patch in the second row (purple).

3. IMAGE REGISTRATION AND ANALYSIS

Because of differences in refractive index of the camera lens for different wavelengths of light, the geometry of the successive images in the multispectral sequence varied from one image to the next, so that no two were in perfect register. Also the treatment in some cases radically altered the parchment, causing substantial distortion to its geometric structure. To make a composite image of all the wavebands it was necessary to put them all into accurate register, using the four holes drilled in each parchment sample as the anchor points for a projective geometric transform (MacDonald *et al*, 2013).

The image of the sample before treatment taken through the 600 nm filter was chosen as the reference and all other images, both before and after treatment, were registered to it. A template matching procedure enabled the centroid of each of the four holes in each sample to be located accurately (Fig. 3 left). Given an approximate starting position, the algorithm incremented the diameter of a circular anti-aliased template in units of 0.1 pixel over the range 12 to 16 pixels (1.0 to 1.3 mm), and the template was successively translated along the x and y axes. At each coordinate position a cross-correlation was performed between the template and the corresponding image section. The accuracy of the registration procedure is shown in the false-colour image composite (Fig. 3 right). The transformed image (red channel) is closely in register with the reference image (blue channel), so that they appear everywhere as a unified magenta.

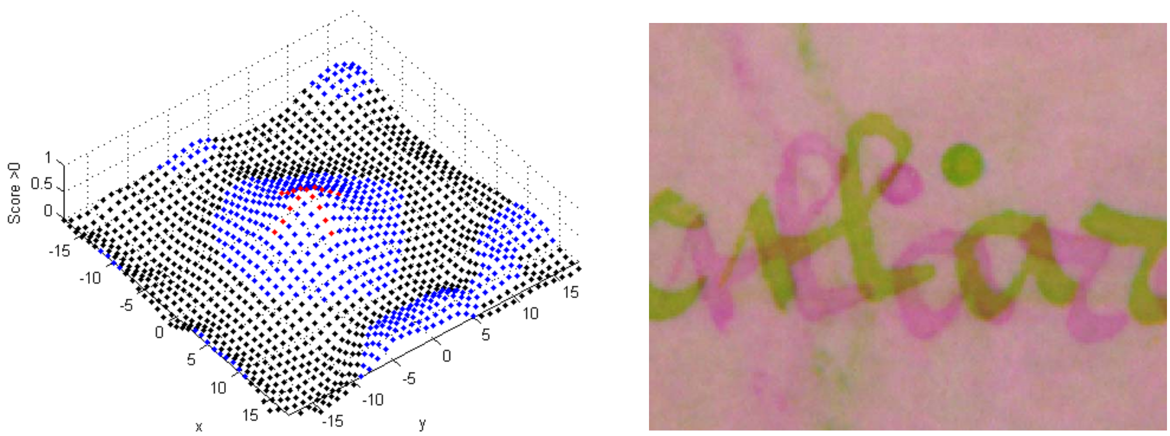

Figure 3: (left) Correlation scores from template matching on one of the registration holes, visualised as a surface on a pixel grid, showing the peak score at the hole centre, and secondary peaks caused by the ink strokes. Scores < 0 are represented by black dots, and scores > 0 by blue dots. The red cross shows the row and column indices of the peak score. (right) False-colour composite of reference 600 nm channel of sample before treatment (blue), 850 nm channel of sample after treatment (green), and the latter after registration (red).

When all of the image channels for the sample before and after treatment had been accurately registered, it was possible to compare the reflectance spectra at any pixel position. Fig. 4 shows the effect of the treatment by blood on the parchment and iron gall ink. The spectra are plotted for all nine pixels in a 3x3 pixel region around the selected coordinates, together with the mean in green (before) and red (after). The blood clearly affected the colour of the parchment, reducing its reflectance factor from about 0.5 to less than 0.1 in the short wavelengths, rising to about 0.4 at long and NIR wavelengths, producing a dark red colour. The ink spectrum was apparently not much changed except at wavelengths greater than 850 nm.

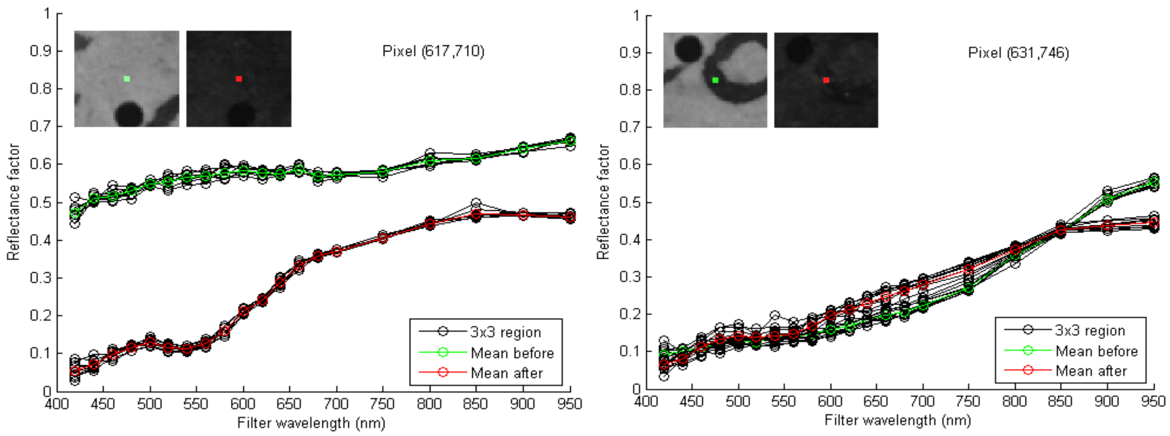

Figure 4: Reflectance spectra before and after treatment for (left) parchment and (right) ink.

A typical problem where a degraded parchment is subjected to analysis is that its original state (both text and material) is not known, and so assumptions must be made in guiding the digital restoration. Our dataset of the parchment samples before treatment provides a 'ground truth' for analysis of the effectiveness of image processing algorithms in restoring images of the degraded samples. Our dataset of the samples after treatment shows exactly the effect of the physical changes on the reflectance. Analysis of multispectral images of scraped or mechanically damaged samples enables us to identify even faint traces of ink. It also enables the discrimination of inks similar in appearance, and the recovery of writing from darkly stained parchment and from charred and burned fragments. Because the reflectance spectrum can be estimated from the multispectral image set, the appearance of the parchment under any illumination source of known spectral power distribution can also be predicted.

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