Multispectral Imaging of a Botanical and Zoological Compendium

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1. Introduction

The covers of a book from UCL Special Collections called *Exoticorum libri decem* (or ‘Ten books of exotic life forms’) underwent multispectral imaging at UCL’s Digitisation Suite. The Latin text, written by Charles Del’Ecluse or in its Latin form Carolus Clusius, and published in Leiden, Netherlands in 1605, is a botanical and zoological book containing many ornate illustrations such as in figure 1. The binding, as described on UCL Library Services Explore, is an “old binding of blind-stamped vellum over boards, part stained” (see figure 2). Angela Warren-Thomas, conservator at UCL Special Collections, wished to ascertain whether the vellum contained hidden text due to the markings apparent on the surface, and thus requested that multispectral images be captured with the aim of uncovering what is beneath.

![Figure 1: An illustration of a creature at the bottom of page 94.](image-url)
2. Method

The R.B. Toth Associates multispectral imaging system comprises a 60 megapixel, monochromatic PhaseOne camera, two light panels which illuminate in 12 wavelengths from 370 nm in the ultraviolet to 940 nm in the infrared, and a six-position filter wheel containing an ultraviolet bandpass\(^1\) filter, and four longpass filters\(^2\) attenuating wavelengths longer than violet, green, red and infrared.

Multispectral images were captured of both covers of the book illuminated in a range of wavelengths from 370 nm in the ultraviolet to 940 nm in the infrared. Using various different longpass filters, images of both the reflectance and fluorescent light were acquired (see table 1 for the details of the capture sequence). Flat field images, i.e. images of a white piece of card captured in the same conditions as that of the artefact,

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\(^{1}\) A bandpass filter is a filter which allows only a band of wavelengths to pass through by cutting off wavelengths that are shorter or longer than specific endpoints.
\(^{2}\) A longpass filter is a filter which allows light which has wavelengths longer than a certain threshold to pass through.
were acquired to record the distribution of the lighting. The multispectral images are divided by the flat field images to correct the non-uniform lighting.

Table 1: Table containing the details of the capture sequence

<table>
<thead>
<tr>
<th>Index</th>
<th>Wavelength</th>
<th>Colour</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>370</td>
<td>Ultraviolet</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>448</td>
<td>Deep Blue</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>476</td>
<td>Blue</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>499</td>
<td>Cyan</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>519</td>
<td>Green</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>598</td>
<td>Amber</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>636</td>
<td>Red</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>700</td>
<td>Infrared</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>735</td>
<td>Infrared</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>780</td>
<td>Infrared</td>
<td>None</td>
</tr>
<tr>
<td>11</td>
<td>870</td>
<td>Infrared</td>
<td>None</td>
</tr>
<tr>
<td>12</td>
<td>940</td>
<td>Infrared</td>
<td>None</td>
</tr>
<tr>
<td>13</td>
<td>370</td>
<td>Ultraviolet</td>
<td>Violet (400 nm)</td>
</tr>
<tr>
<td>14</td>
<td>370</td>
<td>Ultraviolet</td>
<td>Green (515 nm)</td>
</tr>
<tr>
<td>15</td>
<td>370</td>
<td>Ultraviolet</td>
<td>Red (590 nm)</td>
</tr>
<tr>
<td>16</td>
<td>448</td>
<td>Deep Blue</td>
<td>Green (515 nm)</td>
</tr>
<tr>
<td>17</td>
<td>448</td>
<td>Deep Blue</td>
<td>Red (590 nm)</td>
</tr>
</tbody>
</table>

The images were then processed using various image processing techniques in ImageJ\textsuperscript{3}. These included principal component analysis (PCA), histogram equalisation, image complements and the D-Stretch algorithm.

PCA is a statistical technique used for reducing the dimensionality of a sequence of images and for feature extraction. PCA creates a new sequence of images called principal components, in which the covariances between the original images are minimised. Therefore, it is often applied to sequences of multispectral images in order to emphasize variation and produce strong patterns in data sets. The first few principal

\textsuperscript{3} ImageJ is a free image editing software, available \url{https://imagej.net/Welcome}. 
components contain the majority of features contained in the entire original sequence of images and these features are enhanced. In the principal components, the grey levels have no practical meaning and thus, the text may appear white or black.

Histogram equalisation enhances the contrast in an image by redistributing the grey levels equally over the entire range from white to black. The histogram of an image visually displays the number of pixels containing each grey level. Histogram equalisation ensures that the image does not contain a large amount of dark or light areas, but instead an even spread of grey levels. This is an easy, fast and effective technique for contrast enhancement but unfortunately, increases the contrast of background noise as well and thus the processed images are noisier than the originals (compare figures 6 and 7). Figure 3 shows the histograms of the fourth principal component before and after histogram equalisation. The second histogram contains a wider spread of grey levels and the frequency of the original grey levels has decreased significantly, thus flattening the shape.

Image complements are effective at enhancing features that are present in dark regions and so would otherwise be difficult to see. In a grayscale image, the image complement is often called the negative. The black and white values are reversed, and the grey levels in between are flipped so that the dark areas become lighter and vice versa. For a colour image, the colours are replaced by their colour complements according to the colour wheel. Figure 4 shows the histograms for both the fifth principal component after histogram equalisation and its image complement. The histogram is mirrored across the centre of the x-axis between the image and its complement.

The D-stretch algorithm, otherwise known as decorrelation stretching, is a technique used to increase the contrast in colour images by expanding the range of colour values within the image. Therefore, the D-stretch algorithm results in improved visual interpretation and will enhance the difference between features and consequently, make the text stand out more from the background.
Figure 3: Histograms of the grey levels in the 4th principal component before and after histogram equalisation.
Figure 4: Histograms of the 5th principal component after histogram equalisation and its image complement.
3. Results

3.1 Front Cover

*Figure 5: The front cover illuminated in the infrared light with wavelengths centred at 940 nm.*

The multispectral images of the front cover enhanced some of the text (see figure 5) although it did not significantly improve the legibility and, consequently, the language and content could still not be determined.

*Figure 6: The fifth principal component of the front cover showing some text on the vellum.*

The text appeared much clearer in the principal components (see figure 6) than in the multispectral images. However, although some words could be identified, the majority of the text was still indiscernible. The principal components revealed that the text was not present the whole way across the cover, stopping approximately three-quarters of the way across. As a result, the images were cropped so that only the area with the text was processed. The arrow on figure 6 indicates the cut-off point for the text on the front cover. The clearest text appeared on the fourth, fifth and seventh principal components, and was enhanced using various processing techniques such as histogram equalisation and taking the image complement (see figure 7).
The enhanced images of the three principal components were then combined to form colour images (figure 8). The image on the left of figure 8 was created by placing the enhanced images of the fourth, fifth and seventh principal components in the red, green and blue channels, respectively. The d-stretch algorithm was then applied to enhance the difference between the text and the background. The image on the right was created by taking the image complement of the image of the left. To ease with analysis, figures 9 and 10 contain an enlarged, cropped area of the legible text. Finally, figure 11 shows the area at the top of the book cover in which the text is still difficult to read.

*Figure 7: The enhanced images of the fourth, fifth and seventh principal components showing the text more clearly.*
Figure 8: Left shows the colour image created by placing the enhanced images of the fourth, fifth and seventh principal components in the red, green and blue channels, respectively. Right shows the image complement of the left image.
Figure 9: Crop of the lower portion of the text in figure 8 with an arrow pointed to an initial written in a different colour than the rest of the text.
Figure 10: Crop of the lower portion of the text in figure 8 with arrows pointing to two initials written in a different colour than the rest of the text.
Figure 11: A close up of the top half of the text in figure 8 where the text is difficult to decipher.

3.2 Back Cover

Figure 12: Multispectral image of the back cover illuminated in infrared light with wavelengths centred at 940 nm.
As was the case with the front cover, the multispectral images of the back cover did not reveal much of the text (see figure 12). The images were then processed using PCA to see whether the text was enhanced in any of the principal components. Three principal components, specifically the 9th, 15th and 21st, contained parts of the text although many areas were still illegible and the contents remained indecipherable. Figure 13 shows the 15th principal component. The principal components were then further processed using histogram equalisation, image complements and the D-Stretch algorithm similarly as in §3.1. The text in the enhanced principal components was much more legible (see figure 14) and so the three images were combined to form a false-colour image (see figure 15). Figure 15 shows the image created by placing the three enhanced principal components in the red, green and blue channels, respectively, (left) and the image complement (right). Due to the difficulty in reading the text, crops were enlarged into figures 16 -18. The text in figures 17 and 18 appears to touch the edge of the cover and is not parallel to the edges of the book. The text also appears to end part way across the cover as shown by the arrow in figure 13.

*Figure 13: The 15th principal component of the multispectral images of the back cover.*
Figure 14: The enhanced 9th, 15th and 21st principal components.
Figure 15: Left shows the image created by placing the enhanced 9th, 15th and 21st principal components in the red, green and blue channels. Right is the image complement of left.
Figure 16: Crop showing the text at the top of the cover.
4. Discussion

4.1 Front Cover

The text was not clear in the multispectral images, however, after further processing using PCA, histogram equalisation, image complements and the D-Stretch algorithm, it was apparent that text is present on the vellum of the front cover. The text that could be seen in the principal components was only present on part of the cover and not the whole way across, and there was a clear line at which it stopped. When the three principal components that contained the clearest text were combined into a false colour image, the contrast between the text and the background was enhanced still further. The text in the top half of the cover was difficult to identify although some letters and outlines could be seen (figure 11). The text on the lower half of the cover, however, was much clearer (figures 9 and 10). There appeared to be three initials on the front cover which have been written in a different colour to the rest of the text, and one of these is possibly the letter ‘Q’.

4.2 Back Cover

As with the front cover, the text appeared in the principal components but was not visible in the multispectral images. Furthermore, the text was shown to only partially cover the vellum, there being a clear line at which it stopped. Unfortunately, although the 9th, 15th and 21st principal components best displayed the text, these images were also noisy. Furthermore, this noise increased due to the enhancement techniques such as the histogram equalisation. Combining the enhanced principal components into a false colour image showed the text more clearly (see figure 15 which shows the false colour image and its image complement). Some letters had diacritical marks, such as ā and ū, which are common in Latin texts. The word eā appears to be Latin although the exact language of the text is outside the author’s area of expertise. Additionally, three phrases were written in a different colour ink (see figure 15).
5. Conclusion

Text was found to be present on both the front and back stained black vellum covers. This text was not present across the whole of the covers but rather stopped part-way across. Initials on the front cover and phrases on the back cover were found to be written in a different colour ink than the main text. The language may be Latin but this needs confirming by a classics scholar. Unfortunately, the text in the top half of both covers is mostly indecipherable, however, the text in the lower portions is much clearer.