Restaurator, 2007, 11–28
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RESTAURATOR
ISSN 0034-5806

Enhancement of Faint Text Using Visible (420–720 nm) Multispectral Imaging

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INTRODUCTION

Non-destructive techniques that can be used for assessing cultural objects are essential tools for assisting art historians and art conservators. For example, spectroscopic techniques that have been developed for other areas of science have been successfully adapted to the field of conservation. Reflectance spectroscopies using visible and infrared (IR) radiation are well-established techniques that have been used successfully for assessing cultural objects such as paintings[1]. Recently, Cloutis et al. described the use of bidirectional reflectance spectroscopy (0.3–4.3 μm) for distinguishing many white pigments, including $CaCO_3$, $BaSO_4$, TiO_2, ZnO and basic lead carbonate, $2PbCO_3{\bullet}Pb(OH)_2$[2] Discrimination was possible using absorption bands in the 1.0–2.5 μm wavelength range. Unlike IR spectroscopy, visible spectroscopy is often of limited use for the identification of chemical functional groups, however, visible spectroscopy has other applications for studying pigments. Visible spectroscopy has also been used by Goltz et al.[3] for monitoring the darkening of basic lead carbonate, $2PbCO_3{\bullet}Pb(OH)_2$, the pigment used in Flake White, as a result of exposure to H_2S, either from an atmospheric source or from other S-containing pigments. When combined with microscopy, visible spectroscopy has been shown to be very useful for examining individual paint layers[4]. A number of papers have reported on the use of fibre optic reflectance spectroscopy (FORS) for measuring visible and IR reflectance of painted objects[5–10]. The use of a fibre optic cable has the advantage of obtaining point spectra in specific locations on the surface of a painting. Therefore, it has found a number of applications in the investigation of works of art. These applications include: monitoring colour change in some pigments[11], pigment identification[10, 12], pigment quality[13], and detection of alteration products in white calcareous samples[14, 15].

In contrast to point spectroscopy with a fibre optic cable, imaging of conservation objects has become an increasingly important tool for conservators. Imaging can provide the user with 2-dimensional or spatial information of an object. Imaging has also been adapted for the examination of historically important objects that are text-based, such as mediaeval manuscripts[16], the Dead Sea scrolls[17] or the Archimedes palimpsest[18]. Hyperspectral and multispectral imaging using visible and IR digital cameras provide the user with a third dimension of spectral information. Hyperspectral imaging with visible and near infrared wavelengths has been used for examining pigment distributions in a sketch that was altered during a cleaning attempt[19]. In this work supervised (linear discriminant analysis) and unsupervised (fuzzy C-means) classification were used for locating regions where faint traces of ink residue remained. Hyperspectral imaging has also been used for the examination of pigment distributions in sketch and painted artifacts[20–22]. The high penetrating power of near IR for most pigments allows for the spatial examination of pigment distributions of underdrawings.

Infrared spectroscopy has been demonstrated for characterising inks that would be found in historical objects in libraries and archives[23]. In this study Fourier transform IR (FTIR) was used to examine the spectral features of iron-gall inks that were prepared in the laboratory. Multispectral imaging in the visible and near IR has been used to determine chemical inhomogeneity of ethylene and vinyl acetate copolymers for the purpose of document authentication of currency[24]. More recently work has been carried out using visible and near-IR cameras for enhancing the readability of text that was either faint or obscured[25–26].

The subject of our investigation for this project was a bound volume of press copies 'Dinorwic Letters – Outward: 17th Feb. 1905 to 15th May 1905', from the Hudson's Bay Archives (document reference no. B273B). This bound volume is one of seventeen volumes from the Dinorwic post (Ontario, Canada) during this time period and it is part of the collection of the Hudson's Bay Archives that is located in the Archives of Manitoba (Winnipeg, Canada). A few of these press copies contain faint text on leaves of semi-transparent tissue paper. The text consists of letters that were wet transferred from typewritten text of the original letter. On numerous pages the transferred text is quite faint and extremely difficult to read without a visual aid. The text could be faint for a number of reasons; however, the mostly likely cause is poor transfer of ink from the original, which could easily have occurred as a result of insufficient dampening of the original document. Therefore, the objective of this project was to explore the use of hyperspectral imaging for enhancing the legibility of the text in this bound volume. One advantage of this imaging approach is that the digitized images allowed us to explore the use of mathematical approaches such as principal component analysis for enhancing the legibility of the faint text.

Experimental

Imaging was performed using a Nuance Multispectral Imaging System (Channel Systems and CRI). This instrument is equipped with a liquid crystal tunable filter, optics and digital camera with a CCD detector. The image sensor pixel count is 1.3 megapixels and images were 1248 x 960 pixels. Images were acquired from 420 nm to 720 nm at intervals of 10 nm. Data acquisition by the instrument was controlled entirely by a laptop computer. Spatial information is obtained in two dimensions (x, y) and spectral information is obtained in a third dimension (z), which allows the storage of information in a 3-dimensional data cube. The exposure times for each wavelength were entirely computer controlled and varied according to the sensitivity of the system to specific wavelengths of light. For shorter wavelengths (420 nm) exposure times were as long as 30 s and for longer wavelengths (720 nm) exposure times were approximately 1 s.

Lights with incandescent studio bulbs (General Electric) were placed at approximately 45° from the object at a distance of 1 m. Fine positioning of the individual lights was carried out manually to minimize the effects of uneven lighting. The camera was positioned directly in front of the object of interest at approximately 1 m. Individual pages were imaged as right reading text documents such that the imaging took place through the non-transfer side of the page.

In all imaging experiments a data cube of each page was collected followed by a reference cube using a white reflectance standard. The reflectance standard used was a 20 x 20 cm halon (98% reflectance at 550 nm) panel. The data cube was flat fielded by dividing the pixel intensity of the sample by the corresponding pixel intensity from the white cube reference image. This allows for a correction in sensitivity to light across the pixel grid of the CCD detector. Flat fielding also corrects for variation in the intensity of the light source on the image. In order to perform the flat-field calculation for each pixel, light conditions (intensity, position) and exposure times for each wavelength must be identical for both the white cube and the image cube. Reflectance spectra or optical density of the different inks and paper were obtained by calculating the negative log of the reflectance or $-\log(I_S / I_R)$[20]. For all experiments an entire letter on one page was imaged; however, for the purpose of presentation, only a portion of the text is shown in the Figures.

Results and Discussion

The letters, which are found in this bound volume, consist of correspondence that was typewritten on paper and wet transferred to tissue paper for the purpose of archiving[27]. Before the widespread usage of carbon copy paper, copying type-

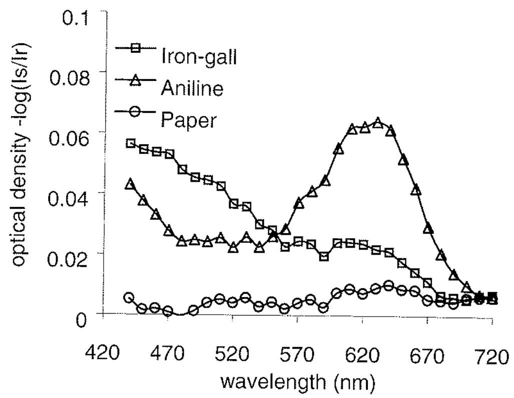

Fig. 1: Reflectance spectra of typewriter ink, iron-gall ink and paper from page 77.

script or manuscript by pressing the original against a damp tissue paper was common. On a number of the pages in the bound volume of this study, the transferred text is so faint it cannot be read with the unaided eye. Except for pages with columns of numbers, the text was transferred from typewritten text and the typewriter ink is likely to be aniline based. Manuscripts of this period often contain information that is hand-written or typewritten with inks that are aniline based[27]. Widespread use of aniline based inks began at the end of the 19th century, as they were generally stable and low-cost.

A signature appears at the bottom of the letters (S.A. King), which appears to be written with different ink, that is dark brown in appearance. A test strip with bathophenanthroline did not give a positive test for Fe^{+2}, which indicates that it may not be iron-gall ink. A small number of pages have columns of numbers, which are similar in appearance and spectral properties as the signature. A test strip with bathophenanthroline gave a positive test for Fe^{+2}, which suggests that these columns of numbers were written with iron -all ink.

On some pages the legibility of the typed text is problematic because of the presence of other inks that had migrated from adjacent pages. This migration was likely to have occurred when the damp pages came in contact with each other either during storage or during the preparation of this bound volume. A good example of this problem occurred on page 77. The transferred iron-gall ink on this page consists of columns of numbers that were accidentally transferred to this page from an adjacent page. As a result of this accidental transfer, page 77 was ideal for testing the feasibility of using visible multispectral imaging for discriminating between the different inks and paper.

Fig. 1 shows the reflectance spectra or optical density of transferred iron-gall ink, the typewriter ink and the paper from page 77. It can be seen that the iron-

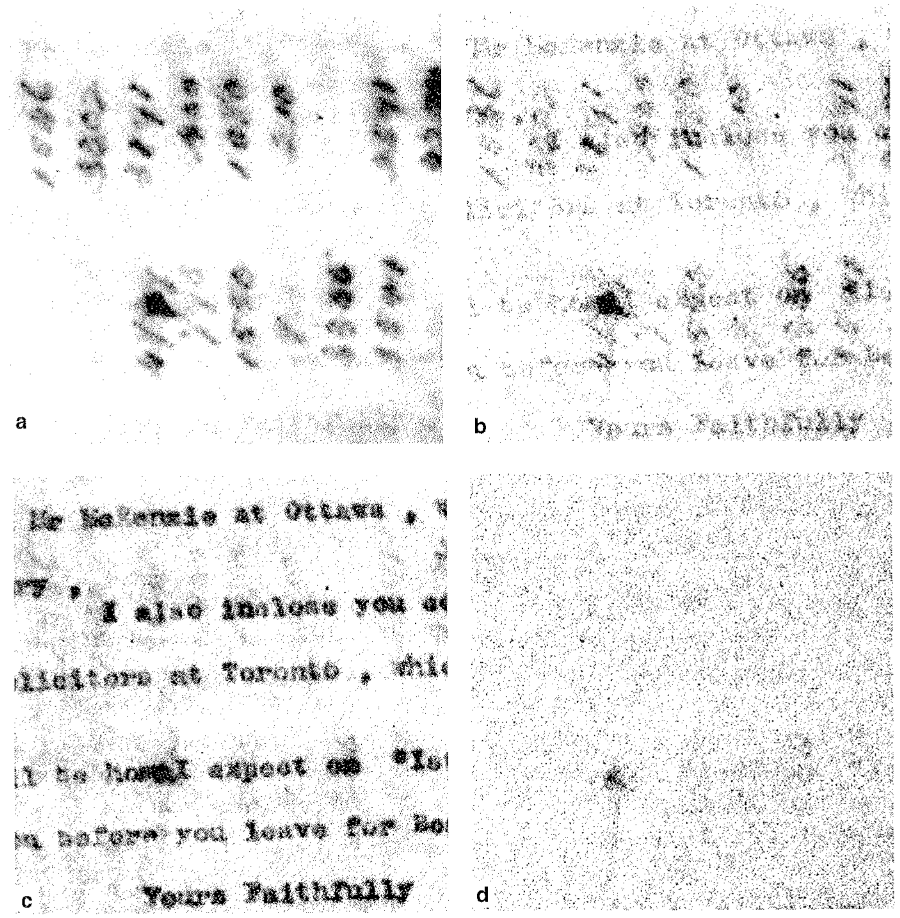

Fig. 2: Images of a portion of page 77 for selected wavelengths: a: 460 nm; b: 550 nm; c: 620 nm; d: 720 nm.

gall ink had higher light absorbance at shorter wavelengths (<500 nm) with no peak absorbance in the visible region. The typewriter ink absorbs longer wavelengths of light and unlike the iron-gall ink, a maximum at 620 nm was observed. The absorbance properties of the two inks made the selection of optimal wavelengths for enhancement of the typewritten text straightforward.

Experimentally, one of the easiest methods for enhancing the typewriter ink text is to examine single wavelength images of the document. In these images, the text has higher absorbance than the paper and therefore appears darker in the image. Fig. 2 consists of a series of single wavelength (460, 550, 620 and

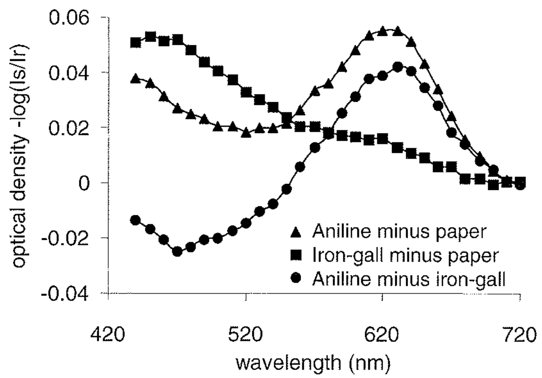

Fig. 3: Difference in reflectance spectra for: typewriter ink minus paper; iron-gall ink minus paper and typewriter ink minus iron- gall ink

720 nm) images of a portion of page 77. In Fig. 2a (460 nm) the faint iron-gall ink that accidentally transferred from an adjacent page can be seen. Absorption of this wavelength of light by the typewriter ink is not evident. At 550 nm (Fig. 2b), the legibility of the iron-gall ink was significantly decreased and the typed text can be detected but not to the point of making it legible. At 620 nm (Fig 2c) the iron-gall ink is essentially undetectable and the typed ink is at the optimal wavelength for text readability. A sharp drop in absorbance occurs at wavelengths longer than 650 nm, and at 720 nm (Fig. 2d) it is apparent that neither ink is visible. As long as the light absorbing properties of the inks and paper are different this simple experiment illustrates the suitability of using single wavelength detection of visible light for enhancing the legibility of these inks.

Difference spectra

Beyond using single wavelengths of visible light, other approaches were examined to determine if further enhancement of the typewritten text could be achieved. One approach that has been used with some success for improving the legibility of the typed text is the application of arithmetic functions or „band math"[24]. To perform these algebraic functions, the image cube was exported into the computer package ENVI ("Environment for Visualizing Images": Research Systems Inc., USA). Algebraic functions can be applied on individual bands (or wavelengths) of the image cube such as the subtraction of pixel intensities of one wavelength from another. In order to logically choose which wavelengths to use, the calculation of differences in optical density was performed for page 77. For this calculation, reflectance spectra were collected in specific regions of interest containing iron-gall ink, typewriter ink and paper. Fig. 3 shows the difference in

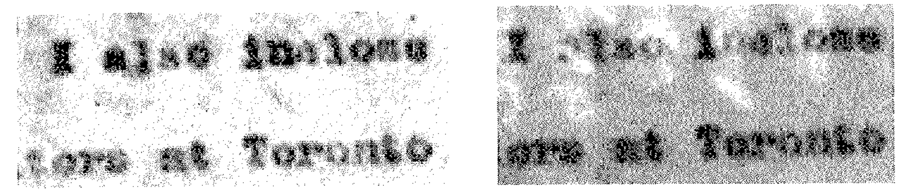

Fig. 4: Text enhancement of a portion of page 77. Comparison of a single wavelength image 620 nm (left) and difference spectra 620 nm minus 470 nm (right).

the reflectance spectra of iron-gall ink minus paper; typewriter ink minus paper and typewriter ink minus iron-gall ink. This graph is useful for indicating the wavelengths where the greatest difference in optical density occurs or which wavelengths would be useful for band subtraction. Specifically this figure shows that the best wavelengths for maximizing contrast and improving the legibility of the typewritten text would be simple band subtraction using 620 nm and 470 nm.

Fig. 4 shows a selected portion of page 77 where the iron-gall ink overlaps some of the typed text. In Fig. 4 (right) the 620 nm band is subtracted from the 470 nm band and in Fig. 4 (left) the single wavelength (620 nm) band is shown for comparison. As expected, when this band subtraction is used, contrast between the typewriter ink and the paper is increased. Specifically, the legibility of typed text is also improved where the iron-gall ink and the typewriter ink do not overlap (i.e. "Toronto"). However where the two inks overlap (i.e. 'I also enclose'), subtraction from the 470 nm band results removal of pixel intensity associated with the typewriter ink, which results in a decrease in the legibility of the typed text. Fig. 4 (right) illustrates that when the 620 nm band is subtracted from the 470 nm band, useful information from the pixels of the typewriter ink text is lost. Subtracting the 620 nm band from longer bands than 470 nm (e.g. 550 nm) can minimize this effect to a certain extent; however, the overall decrease in contrast between the typewriter ink and the paper results in decreased legibility of the text. Therefore, it can be concluded that a reconstructed image from the subtraction of one band or wavelength from another can be useful for enhancing the contrast between typewriter ink and paper. However it should also be noted that the subtraction of one band or wavelength from another is of limited use for improving text readability where the iron-gall ink text overlaps the typed text.

Band substraction

The typed text on page 77 was very faint but legible with a magnifying glass and proper lighting. Other pages in this volume contain typed text that is much more difficult, if not impossible, to read even with the aid of a magnifying glass. Page 42 provides a good sample of typed text that is extremely faint. Interestingly, when the text of this page was imaged, a second layer of text became visible from the accidental transfer from an adjacent page. This created an additional level of background noise, which can be difficult to correct using band subtraction of single wavelengths (620 nm minus 470 nm).

In addition to subtraction of one wavelength from another, an enormous number of algebraic approaches are possible with band math. In any of these approaches the goal is essentially to maximize the areas of the image or pixels with greatest spectral differences while minimizing pixels with the least spectral difference. This can be achieved by simply summing multiple bands (600 + 620 + 640 nm) together to enhance the readability of the typed text. Some enhancement of legibility can be achieved by reconstructing an image from the average of the pixel intensities of three or more bands associated with the typewriter ink (e.g. 600 + 620 + 640 nm) and subtracting them from pixel intensities of three or more bands that are not associated with the typewriter ink (e.g. 450 + 500 + 720 nm). Although this is not shown, reconstructing an image in this manner seemed to improve text readability by reducing the „noise" associated with the paper.

Numerically, differences between the values for pixel intensity of the ink and paper can also be maximized by a squaring function. In other words, contrast between the typed text and paper can be increased when the values of the differences in pixel intensity are squared. A general equation for maximizing the contrast between ink and paper using this approach with band math is:

$$(I_{text} - I_{paper})^m = 2^n$$

where I is the pixel intensity and n is the range of the detector (12 bit $= 2^{12} = 4096$). The term m is determined experimentally after $I_{text} - I_{paper}$ is calculated. For example, if the dynamic range of the detector is 12-bit and the difference in pixel intensity between the ink and the paper is 64, then mathematically the maximum contrast that can be achieved is $64^2 = 4096$. With respect to pixel intensity ($I_{text} - I_{paper}$), the differences were approximately 80–100, so squaring the difference in pixel intensity was feasible for page 42. A reconstructed image of a portion of page 42 with this band math approach is shown in Fig. 5b. When compared to a single wavelength image for page 42 (Fig. 5a), squaring the difference in the pixel intensity improves the legibility of the text by maximizing the contrast or pixel intensity between the typed ink and paper. It is also worth noting that maximizing contrast for the purpose of image enhancement can also be achieved with „tif" files using commercially available software packages such as „Adobe®Photoshop®".

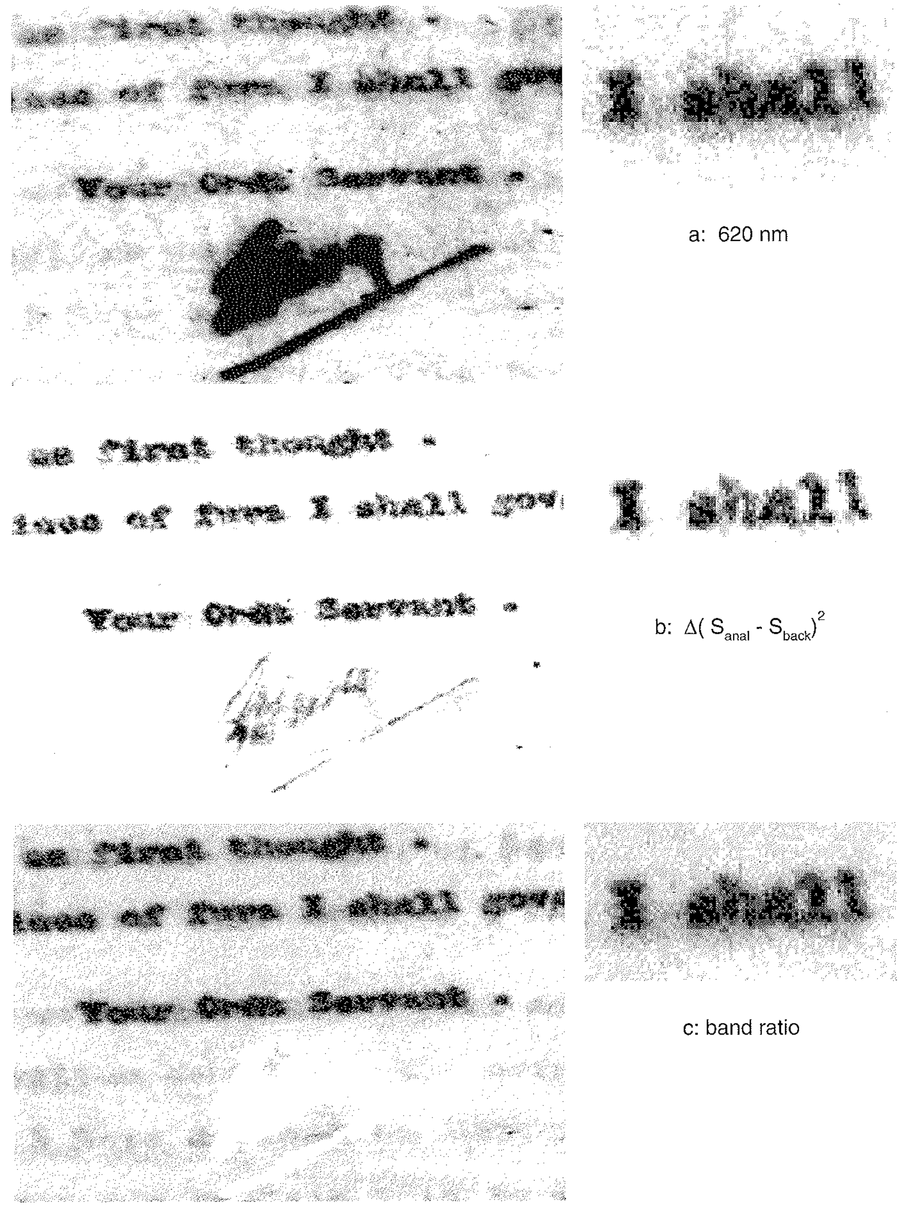

Fig. 5: Text enhancement of a portion of page 42. Comparison of a single wavelength.
a: 620 nm;
b: band subtraction $(I_{ink} - I_{paper})^2$
(I_{ink} = 600+610+620+630+640)/5; I_{paper} = (490+500+700+710+720nm)/5;
c: band ratio: I_{ink}(620 nm) / I_{paper} (470 nm)

Another band math approach that was explored using "ENVI" was band ratios. With band ratios, the intensities at one or more wavelengths can be divided by pixel intensities at one or more different wavelengths. Use of band ratios enhances text legibility by minimizing areas in an image where the two bands of the image cube have common spectral features as well as by maximizing areas in an image where the two bands of the image cube have different spectral features. Fig. 5c is an image of the same portion of page 42 for the ratio of 620 nm : 470 nm. Compared to a single wavelength (620 nm) image (Fig. 5a), the band ratio image appears to have less background noise associated with the paper.

In each of these "band math" approaches there is some degree of experimenting to determine which wavelengths work best. A graph of the optical density (Fig. 2 or Fig. 4) is useful for justifying the use of some wavelengths or rationalizing some of the choices. In each of the experiments a number of wavelengths or bands was examined to confirm the optimal bands to use. It is impossible to conclude that one band math approach is better than other since text legibility for people involves both biological and psychological aspects. In this manner quantitative comparisons are avoided and the user can decide the optimal band math approach with larger portions of text. Smaller portions (i.e. "I shall") are also useful for examining details of the enhancement and actually allow the user to see differences in contrast more readily.

Pixel unmixing

More advanced mathematical techniques are also available to the user and in this work two approaches were investigated. The first approach investigated was "pixel unmixing". The software used to control the Nuance camera also has a useful feature for classifying pixels and unmixing them according to their spectral response. Spectrally mixed pixels result when there is more than one substance located along the optical path, so that the spectrum at a specific pixel is a combination of the spectra of the materials. Since we are using reflectance images the values of pixel intensity in the image cube are converted to optical density. The software then uses a linear combinations algorithm, which assumes that each pixel is made up of a combination of pure spectra. This is achieved by constructing a matrix with *n* pure spectra and *m* spectral channels as well as the contribution of each pure spectrum to a pixel[28]. Instead of pure spectra, the user can select as many pixels as are practical for separating paper and the inks into each spectral class. A grayscale image is then created for each spectrum and each pixel is assigned a fraction of the total pixel intensity.

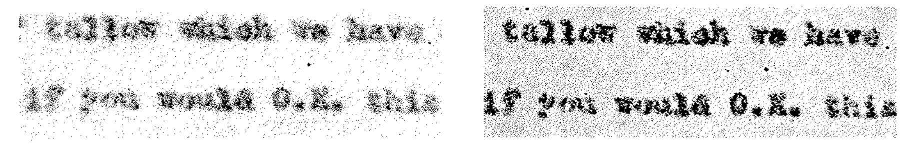

Fig. 6: Text enhancement of a portion of page 26. Comparison of a single wavelength; left: 620 nm; right: pixel unmixing using Nuance software

In this experiment, three classes (typewriter ink, paper, iron-gall ink) of pixels were selected manually from an image cube of page 26. Since the pixels of the typed text were much fewer in number than the paper pixels, proper selection of these pixels was more important than paper pixels for improving the text legibility. In this case it was not unusual to sample a number of different areas or pixels page of 26 to achieve optimal unmixing of the spectral classes associated with the ink and the paper. Once gray scale images for each class are created, the user can then select the appropriate image (or class) of interest, which in this case was from the typewriter ink. Fig. 6 presents two images that show a portion of page 26. A single wavelength (620 nm) image is shown for comparison as well as a reconstructed image from pixel unmixing. Pixel unmixing improved the legibility mainly by increasing contrast between the typewriter ink and the paper; however, compared to the single wavelength image the extent of improvement may not be enough to justify its use on all pages.

Principal component analysis

Another approach that was examined for improving the legibility of the typed text involved the use of Principal Component Analysis (PCA). Numerous books on multivariate statistics and PCA have been published which describe the mathematics of this statistical approach[29, 30]. The principal components of an image can be defined in terms of covariance of their reflectance for each wavelength. The input data contained 1248 x 960 = 1,198,080 pixel intensity values for 31 wavelengths. This allowed us to calculate 31 eigenvectors from the covariance matrix. The eigenvector with the highest eigenvalue is the first principal component of the data set. An image that is reconstructed from the 1st principal component contains most of the variance and therefore, can be very similar in appearance to the original image. The 2nd principal component captures the variance that is orthogonal to the 1st principal component and the 3rd principal component captures the variance that is orthogonal to the 2nd principal component and so on. As a result the amount of information that is contained in the 2nd or

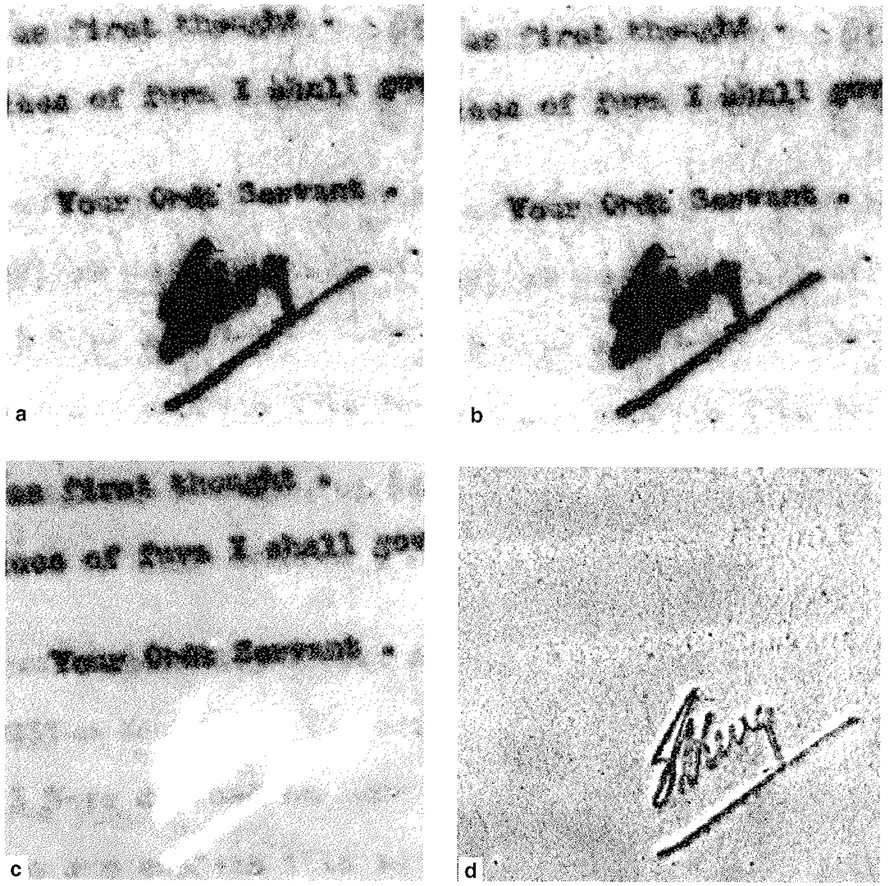

Fig. 7: Text Enhancement of a portion of page 42.: Comparison of a single wavelength image and principal components analysis; a: 620 nm; b: 1st principal component; c: 2nd principal component; d: 3rd principal component.

3rd principal components is often useful as it often shows areas with greater contrast between the typewritten ink and paper than the 1st principal component.

The first five eigenvalues for page 42 were 60.3 %, 8.79 %, 3.45 %, 2.29 % and 1.74 %. These values indicate that most of the variance exists in the first three principal components. Gray scale images were created for the first three principal components of page 42 and are shown in Fig. 7 (b, c, d). For comparison a single wavelength image (620 nm) is also shown (Fig 7a). From the images it is clear that the 2nd principal component is the most useful for enhancing the legibility of the typed text. The 2nd principal component also had less noise associated with

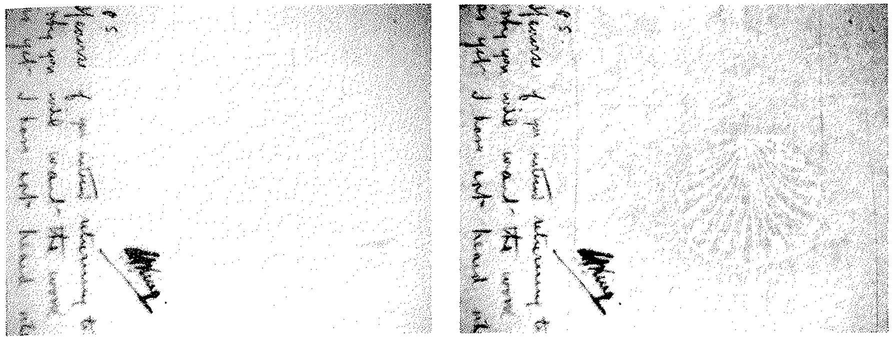

Fig. 8: Single wavelength (490 nm) images of a portion of page 21 to illustrate the effect of reflected (left) and transmitted light (right) for imaging watermarks.

the paper, which made the typed text a little easier to read. Another interesting aspect that came out of this imaging approach is the ability to detect typewriter ink that accidentally transferred from an adjacent page. This text appears predominantly at the bottom of the page and is at a slightly different angle than the intended text. Apart from the typed text, the signature at the bottom of the letters on most pages is often difficult to read. On most pages the signature ink is darker than the typed ink, however, as a result of the transfer to this volume, the signature is somewhat smeared in appearance. Single wavelength images (620 nm) only provide a marginal improvement in the legibility. Fig. 7d, which shows the 3rd principal component, provides a very clear view of the signature Samuel Alexander King, "S.A. King", who was the post manager in Dinorwic during this time.

Transmitted light

Since the pages in this volume were very thin and semi-transparent, imaging was also possible using transmitted light through the page from the source. Casual inspection of the object seemed to suggest that the iron-gall ink was more legible to the unaided eye when the imaging was set up in transmittance mode with the light source behind the pages. For this reason, an imaging experiment was conducted to determine the feasibility of using transmitted light for text enhancement. Unfortunately, imaging with transmitted light was not useful for enhancing the legibility of the type written text. The problem with this approach was the inability to flat-field the light source with a white cube when imaging with transmitted light. The main reason for this was that light conditions (intensity, position) could not be identical for both the white cube and the image cube when transmitted light was used. This experiment did reveal the usefulness of transmitted light for examining subsurface details of the pages. Fig. 8 shows single wavelength (490 nm) images of page 21 using a reflected light source and a transmitted light source. On this page a faint watermark is visible in the form of a seashell. Although only single-wavelength images are shown for page 21, the watermark showed up reasonably well over most visible wavelengths.

Conclusion

Enhancement of text legibility can be achieved a number of ways with hyperspectral imaging in the visible wavelength range. Differences in the absorption properties of the copy paper, typewritten ink and the iron-gall ink, indicates that the use of single wavelengths provides a meaningful enhancement of the faint text on most pages. The hyperspectral images in combination with data of the spectral properties of the constituents of an object, greatly facilitate the choice of the image-processing algorithm to maximize text enhancement. Mathematical approaches such as band math, pixel unmixing and PCA are extremely powerful tools for distinguishing paper and ink in an image cube by their different spectral properties. In this study, distinguishing the different spectral properties of different inks was less critical than distinguishing spectral properties of the faint typewriter ink from the paper it was written on. As a result of this, pixel unmixing and PCA proved to be quite useful for improving the legibility of the faint typewritten text in a bound volume, especially for pages where iron-gall ink overlapped the typewriter ink. For the item under research it would be unnecessary to use mathematical approaches such as PCA on pages where there was only text consisting of the faint typewritten text. For these pages, images consisting of single wavelengths (e.g. 620 nm) were sufficient for enhancing the legibility of the faint text.

Apart from improving the legibility of the typewritten text, modern imaging technology also provides the conservator with the benefit of digitization, which has already revolutionized the way in which archival information is stored[31]. Accurate images of fragile or valuable cultural heritage objects can be stored in a virtual museum or conservation laboratory and no longer need to be inaccessible to the general public. Spectral information is complementary to spatial information and provides another dimension of information for both conservators and researchers.

Acknowledgements

Funding from the Canada Foundation for Innovation (CFI), the Manitoba Research and Innovation Fund (MRIF), the National Sciences and Engineering Research Council of Canada (NSERC) and the University of Winnipeg is gratefully acknowledged by the authors. The authors would also like to thank Mr. R. Ridgen A. Rekrut of the Archives of Manitoba for their support and assistance with this project.

Summaries

Enhancement of Faint Text using Visible (420–720 nm) Multispectral Imaging

Hyperspectral imaging using a digital camera equipped with an integrated tunable filter was successful in improving the legibility of text in a bound volume of press copies (circa 1905) from the Hudson's Bay Company Archives. Much of the faint text had been produced from ink that was wet-transferred from the typewritten text of original documents. The transferred typewritten ink was faint, probably as a result of poor transfer of the original to the copy paper. Consequently, this text is not legible without the aid of either an optical microscope or magnifying glass. On some of the pages, the typewriter ink text is further obscured by text of iron-gall ink or typewriter ink that had migrated from adjacent pages in this bound volume.

Single wavelength images from a Nuance multispectral camera made it possible to distinguish the different inks that overlapped each other spatially. The iron-gall ink absorbed light at shorter wavelengths (<500 nm) and the typewriter ink had a broad absorption band that peaked at 620 nm. Single wavelength images at 620 nm were often sufficient for improving the legibility of the typewriter ink text on most pages. For pages where the typewriter ink text was very faint, more advanced image enhancement approaches such as calculation of band ratios and principal component analysis (PCA) were useful for improving the legibility of the text.

Imaging was carried out both in reflectance and transmittance mode, however improving the readability of the text was most successful using reflected light. This was largely due to the inability to properly flat-field the image when a transmitted light source was used.

La mise en valeur de textes difficilement lisibles à l'aide de l'imagerie multispectrale dans la lumière visible (420-720 nm)

L'imagerie multispectrale réalisée grâce à l'utilisation d'une caméra numérique équipée d'un filtre adaptable intégré s'est révélée être un moyen approprié pour favoriser la lisibilité du texte contenu dans des copies de feuilles en copy press d'un volume relié (en 1905 environ) émanant des archives de la Compagnie de la Baie d'Hudson. La majeure partie du texte défraîchi a été reproduite à partir de l'original écrit à la machine alors que l'encre n'avait pas encore séché. La pâleur est peut-être dûe à une défaillance des moyens au moment du transfert. Ces textes ne sont donc lisibles que grâce à l'utilisation d'instruments techniques tels que les verres optiques grossissants comme la loupe. Sur certaines des pages la lisibilité des textes est encore aggravée par l'érosion de l'encre gallique ou par la couleur du rouleau d'encre qui a déteint sur les pages avoisinantes.

Des images réalisées à une certaine longueur d'onde fixe par une caméra multispectrale à « nuance » ont permis de différencier les diverses encres et couleurs aux endroits où celles-ci se superposaient. On a démonté que l'encre gallique absorbait la lumière à une moins forte longueur d'onde (<500 nm) alors que l'encre de machine avait une plus large bande d'absorption qui va jusqu'à 620 nm. Afin de faciliter la lisibilité du texte qui avait été rédigé à la machine les images produites à une longueur d'onde de 620 nm semblaient suffire dans la plupart des cas. Dans les cas où le texte était plus effacé il a fallu utiliser des méthodes plus compliquées, c'est-à-dire des méthodes mathématiques pour améliorer la qualité de l'image, telles que le calcul des relations des différentes bandes entre elles ainsi que l'analyse PCA (Analyse des principaux constituants).

Les analyses optiques ont été conduites tant à l'aide de la lumière incidente qu'avec la lumière transmise. On a pu démontrer que l'utilisation de la lumière incidente apportait de meilleurs résultats pour l'amélioration de la lisibilité des textes. Ceci est largement dû au fait que dans le cas d'une lumière transmise il n'y a aucune possibilité mathématique de réduction optique.

Die Verdeutlichung verblaßter Text mit Hilfe von Multispektralbildern im sichtbaren Licht (420–720 nm)

Hyperspektralbilder, hergestellt mit einer Kamera, die mit einem integrierten anpaßbaren Filter ausgestatten war, erwiesen sich als geeignet zur Verbesserung der Lesbarkeit von Kopierpressen-Kopien in einem gebundenen Buch (ca. 1905) aus dem Archiv der Hudson's Bay Company. Große Teile der verblaßten Schrift waren im feuchten Zustand von dem maschinengeschriebenen Original übertragen worden. Die Blässe geht möglicherweise auf Mängel bei der Übertragung zurück. Diese Texte sind ohne Hilfsmittel wie Mikroskop oder Lupe nicht lesbar. Auf einigen Seiten wird die Schrift zusätzlich verundeutlicht durch Eisengallustinte oder Farbe vom Schreibmaschinenfarbband, die von den benachbarten Seiten abgeklatscht wurden.

Bilder, hergestellt in einer „Nuance" Multispektralkamera bei fester Wellenlänge ermöglichten es, Unterschiede zu erkennen zwischen verschiedenen Tinten- bzw. Farbtypen, wo sich diese überlappen. Eisengallustinte absorbiert Licht von kleiner Wellenlänge (<500 nm), während Farbbandfarbe in einem breiten Bereich um 620 nm absorbiert. Zur Verbesserung der Lesbarkeit des Textes, der auf Maschinenschrift zurückgeht, genügten meist die bei 620 nm hergestellten Bilder. Wo dieser Text verblaßt war, mußten kompliziertere, d.h. mathematische Methoden der Bildverbesserung eingesetzt werden, wie z.B. die Berechnung des Verhältnisses der verschiedenen Banden zueinander und PCA-Analyse.

Die optischen Untersuchungen wurden sowohl mit Auf- als auch mit Durchlicht durchgeführt. Es zeigte sich, daß zur Verbesserung der Lesbarkeit die Arbeit mit Auflicht die besseren Ergebnisse bringt, vor allem deshalb, weil bei Durchlicht keine angemessene mathematische Bildreduktion möglich ist.

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