Background Correction in Forensic Photography

Gordon M. Miskelly and John H. Wagner
Forensic Science Programme, Department of Chemistry,
The University of Auckland, Auckland, New Zealand
g.miskelly@auckland.ac.nz

Abstract

Traces of enhanced or unenhanced forensic evidence are often found on dirty or patterned substrates, and so images require correction for this background. We have been investigating using background correction techniques to enhance the visibility of compounds that have sharp spectral features (FWHM < 50 nm) compared to many colorants that occur in the human environment. Our initial investigations have focussed on the use of cameras and light sources likely to be already present in a forensic laboratory.

Keywords: forensic, photography, background correction

1 Introduction

The use of spectral information to isolate specific patterns in an image is well known in many fields including remote sensing and astronomy [1]-[3]. The technique is less evolved in forensic imaging, with the most common spectral selection involving taking images with filtered illumination or a filter on the camera, or subtracting two such images taken at significantly different wavelengths.[4]-[9] We have been studying the specific enhancement of analytes with comparatively narrow spectral features (full width at half maximum (FWHM) of the absorbance peak being less than 50 nm), with blood as our first target. Blood is characterised by a very intense aborption (the Soret band) near 415 nm, with a FWHM of approximately 30 nm. The band position and shape vary slightly depending on the age and oxidation state of the blood. Blood stains are a common form of evidence at a crime scene or on items obtained from a crime scene. These stains frequently occur on patterned or dirty substrates, and the shape and size of the substrate will often make it difficlt to obtain uniform lighting across the item. We therefore sought an imaging technique that could remove variability due to the substrate patterning and the lighting.

The image enhancement technique was also developed in an attempt to reduce the use of chemical enhancement agents at a crime scene. Thus, if sufficient information can be gained by appropriate imaging techniques there is no need to further enhance the bloodstain. This reduced chemical usage at crime scenes has the advantages of reduced exposure for investigators and people using the area after the investigation, and also reduces the chance that the chemical enhancement could affect later analysis such as DNA profiling.

The image enhancement technique chosen is based on the narrowness of the Soret band of blood. Most colorants in the human environment have comparatively broad spectral features, often with FWHM over 100 nm, or features which extend continuously into the UV region. Therefore a sharp spectral feature can be isolated by using bracketing wavelengths to estimate the background absorbance. In the case of blood this can be done by using images taken using light centred at 395 and 435 nm to estimate the background and comparing this to an image taken with light centred at 415 nm. This technique has been used in clinical chemistry for many years to isolate the absorption due to blood from other interferents in solutions such as urine.[10]-[13] However, it does not appear to have been applied previously to two-dimensional images. Furthermore, we have implemented integrated forms of the transmittance and reflectance equations rather than the usual form based on intensity:

Corrected transmittance at 415 nm

$$\approx \frac{2I_{transmitted,415nm}t_{415nm}}{I_{transmitted,395nm}t_{395nm} + I_{transmitted,435nm}t_{435nm}} \quad (1)$$

Corrected reflectance at 415 nm

$$\approx \frac{2I_{reflected,415nm}t_{415nm}}{I_{reflected,395nm}t_{395nm} + I_{reflected,435nm}t_{435nm}} \quad (2)$$

where t_{xnm} is the exposure time at wavelength x nm and $I_{transmitted,\ xnm}$ and $I_{reflected,xnm}$ are the transmitted and reflected light intensities at x nm detected by the camera respectively. The justification for these approximate equations has been published previously. [14],[15]. Initial studies have used a consumer digital camera, standard image processing software, and a forensic alternative light source, since these items are likely to be found in many forensic laboratories. Our

investigations have shown that it is indeed possible to obtain good results with this equipment, although more specialized equipment and software is likely to provide faster and better imaging.

2 Experimental

The camera used was a Canon D-30 digital SLR camera (2160 x 1430 pixels), with either a Canon 24-85 mm zoom lens or a Canon 100 mm F2.8 USM macro lens. This camera is equipped with a CMOS sensor combined with proprietary noise reduction facilities. The camera was controlled with either the supplied Remote Capture (Canon) or with D30Remote (Breeze Systems). The light source was a Rofin PL-10 Polilight forensic light source, which is a high intensity xenon lamp with selectable narrow bandpass filters which can be tilted to achieve fine alterations of the bandpass maximum. The filters have nominal bandpasses ranging from 40 to 80 nm.

The camera has a Bayer mosaic to provide the RGB image, so the RGB information at any given pixel is an interpolated value. Resolution issues associated with this problem were ignored in this study because all bloodstains examined were significantly larger than the resolution limit.

The images were captured in the camera's linear mode in the proprietary Canon RAW format (12 bit per channel RGB). These were subsequently processed to give 16 bit per channel TIFF files using ZoomBrowser (Canon). Image processing was performed using Photoshop 6.0 (Adobe Systems) in 16 bit mode with the Fovea Pro 2.0 (Reindeer Systems) image processing plugins. Images so obtained contain RGB channels with brightness levels given in the range 0 – 255 with fractional levels possible for > 8 bit images.

Correct image exposures were obtained in a number of ways. Frequently, the camera's autoexposure feature provided adequate exposure estimates. Alternatively, a gray scale card (Kodak or QPcard) was included in the image and used for pre or post image exposure calculation or correction. Finally, the relative sensitivity of the light–filter–camera combination was calculated by experience so that the relative exposures could be programmed to the camera. In our particular arrangement the light throughput at the different wavelengths was such that the relative exposure times were approximately 1 (435 nm) : 10 (415 nm) : 100 (395 nm). This rapid change with wavelength is due both to the light source intensity profile and the spectral sensitivity of our RGB camera.

Images were processed by averaging the images taken at 395 and 435 nm, then ratioing this image with the image taken at 415 nm. This ignores the contribution of any dark current to the images. However, we determined that the dark current did not contribute significantly to well-exposed images taken with short exposure times, and at longer times we used a noise reduction feature on the D-30 which incorporates an automatic dark current correction for each individual exposure. For a picture taken in transmission mode the ratio image so obtained rigorously gives the transmittance at each point in the image which can then be related directly to the amount of absorber between the light source and the camera. For images taken in reflectance mode the relationship to amount of absorber is not as straightforward, and Fresnel reflection can cause artefacts for some blood stains. However, in general, use of the above image ratio provides good enhancement of blood stains in reflectance mode as well.

Items photographed using this technique included (in reflectance mode) casework items from ESR Ltd. and items deliberately stained with bovine blood and potential spectral interferents such as coffee and tomato sauce, and (in transmission mode) dilute solutions of bovine blood.

3 Results

The camera was first evaluated to see whether it met nominal noise specifications and bit depth. Analysis of within– and between– image variability of RGB images showed that there was a constant 0.9% relative standard deviation (n=10 images) in pixel intensity between images. The Photon Transfer Curve (with the noise calculated using a difference image) showed that the camera noise was shot-limited over most of its exposure range, and that the noise scaled with ISO setting.[16] If only the blue pixels (i.e. data prior to Bayer interpolation) are examined then the full well capacity is approximately 22 000 and the dynamic range is 830, corresponding to an effective bit depth of 9.7 at ISO 200. Noise values calculated from pixel values in the RGB TIFF file derived from the initial camera data (which have been subjected to data processing including Bayer interpolation) are significantly decreased compared to the "off-the-sensor" data. The amount of noise observed in the RGB image suggested that the camera had a dynamic range of 2250 (67 dB) at an ISO setting of 200. This corresponds to an effective bit depth of 11.1 compared to the nominal 12 bits per channel. These values depend on the ISO setting, with the dynamic range and effective bit depth dropping to 1350 and 10.4 respectively at the ISO 400 setting.

For most image analysis of blood in Adobe Photoshop only the blue channel was used, since this is the most sensitive at <450 nm. This channel selection was done in preference to converting the complete RGB image to monochrome, since the other two channels would have contributed little signal and a significant amount of noise to the image. It should be noted that even though the camera has 3.1 megapixels due to the Bayer pattern only one quarter of these are sensitive to light near 415 nm.

The method of ratioing an image taken at 415 nm to the average of images at 395 and 435 nm corrected for changes both in the illuminating light intensity and background variation as long as the exposure times were chosen appropiately. This approach differs from most other approaches where information is used from different spectral regions, since more commonly equal exposures are used at each wavelength. This latter approach requires that an estimate be made of the incident light intensity at each wavelength and there can be problems if the intensity of light detected at the wavelengths varies greatly. The present approach avoids these problems and works as long as the three chosen wavelengths are relatively close together so that the bracketing wavelengths provide a good approximation to the background at the wavelength of interest. Photographs of blood solutions (in petri dishes) taken in transmission mode using equation 1 showed that the camera behaved as a linear detector and subsequent data analysis indicated that the absorbance of the blood was proportional to concentration over a range of 100 to 2000 fold dilutions.

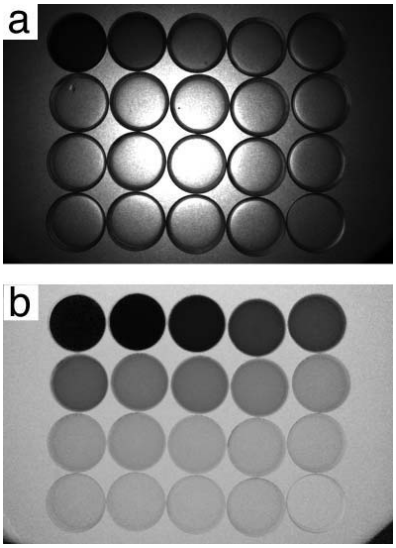

Figure 1: Images of diluted blood taken in transmission mode. a) Image taken with illumination at 415 nm. b) Image obtained by performing background correction according to equation 1. Blood dilutions range from 50 to 5000, with plain water on the bottom right.

The camera started showed non-linearity when pixel brightnesses in the RGB image exceeded 160, and excessive noise compared to signal when pixel brightnesses were below 6, so that images were exposed to maintain most of the region of interest in any image within this range. Regions of the image where pixel brightnesses were outside these limits sometimes led to artefacts which could be mistaken for blood. These regions could be removed by appropriate masking of the image based on pixel brightness. The upper limit of 160 is a consequence of scaling occuring during the Bayer interpolation and associated processing, since the uninterpolated values saturated at values in the range 240-250.

The limit of detectability of blood on a range of substrates was examined, and compared with visual examination and photography at a single wavelength range (centred at 415 nm). On monocoloured substrates the limit of detectability was also calculated using the ratio of images taken at 415 nm and 435 nm, since the 395 nm image was typically more noisy than either of these. This dual wavelength ratio could not be used as successfully on patterned images, where the 395 nm information was necessary to perform adequate background correction. On off-white cotton bloodstains could be observed when diluted 400 times (illumination at 415 nm) and 1000-1600 times (images processed using equation 2 or by ratioing photographs taken at 415 nm and 435 nm). On dark blue denim similar relative improvements were observed although the detection limit was approximately ten times worse.

The method enables images to be obtained that clearly show patterning while the background changes significantly in overall brightness, as shown in figure 2. This can be useful where a pattern (such as a shoeprint) provides identifying information.

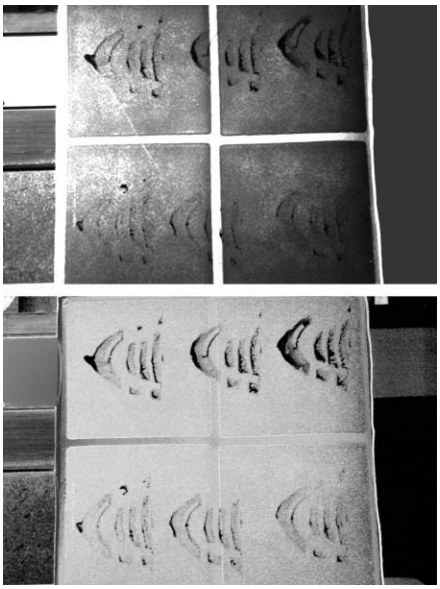

Figure 2: Images of shoeprints in blood on a red tile square. Prints were obtained by placing blood on a portion of shhoe sole and sequentially stamping it on the tile from top right to left then bottom right to left. Top image was taken at 415 nm. Lower image was obtained by performing background correction according to equation 2. Both images have been adjusted for optimal brightness and contrast.

On patterned substrates the background correction using equation 2 with the three images at 395, 415, and 435 nm was even more effective compared to direct visual examination or an image taken at 415

nm, as illustrated in figure 3. This image is of blood on a floral patterned fabric, with blue, green, and pale orange being the predominant colours. In this case two wavelegth ratioing does not remove the background variation because the different colours have significantly different spectra in the region 390 – 450 nm.

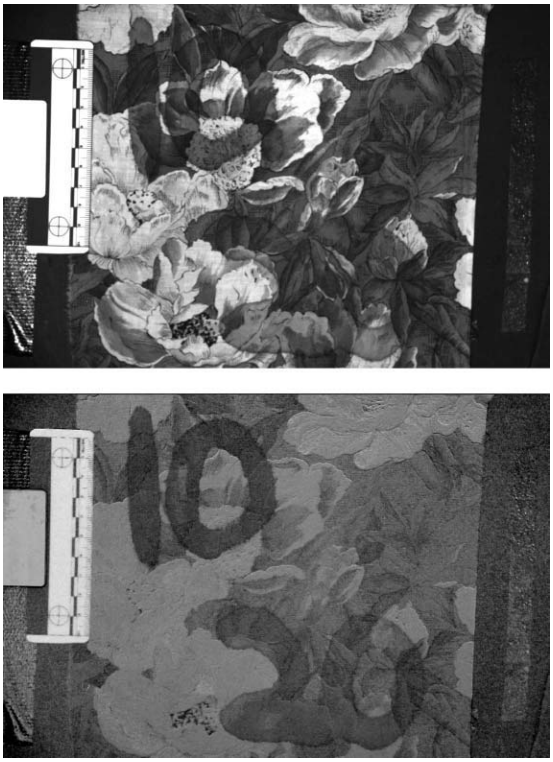

Figure 3: Images of 10-fold and 20-fold diluted blood on a floral substrate. Top image was taken at 415 nm. Lower image was obtained by performing background correction according to equation 2. Both images have been adjusted for optimal brightness and contrast.

4 Discussion

The background correction method has been shown to be an effective way of enhancing bloodstain evidence compared to any patterned substrate, and also removes effects due to uneven lighting. The derived equations for the background correction are rigorously correct in transmission mode (equation 1), and equation 2 appears to be a good approximation in reflectance mode as well. It is likely that for more quantitative analysis in reflectance mode equations based on the Kubelka-Munck treatment will be more appropriate.

In transmission mode the imaging system has been shown to provide quantitatively correct background correction up to an effective absorbance of about 1 even though the bandwidths of the illuminating light are wider (ca. 50 nm FWHM) than is appropriate for quantitation of the Soret Band (25 nm FWHM). We have investigated using narrow bandwidth filters (10 nm FWHM) on the camera, but image misregistration due to slight optical nonuniformity in the filters has meant that these filters have not provided improved detection in our current configuration.

The background correction technique was tested on a number of forensic case items from ESR Ltd. to determine whether the method offered significantly improved performance compared to their standard bloodstain visualisation protocol. In particular, dark items and patterned items were examined. Blood stains on black or dark blue denim can be difficult to detect visually, particularly if the clothing is dirty. Photography using illumination at 415 nm offers improved analysis, but clothing items frequently have folds and creases which makes uniform lighting difficult. In addition, the forensic alternative light sources provide a filtered light beam of finite size and with a radial intensity distribution, which again means that uniform lighting is often not possible. For these reasons the ratioed image offers significant benefits, particularly if it can be automated.

The technique can also be used with other compounds with sharp spectral features such as the product formed when ninhydrin-treated fingerprints are reacted with $ZnCl_2$ solution. Ninhydrin is used to visualise latent fingerprints on paper, and reacts with amino acids in the fingerprint to for a dark blue/purple coloration. The subsequent zinc treatment forms a fluorescent complex which appears pale pink (i.e. much more faint) to the naked eye. However, this pale pink zinc complex has an absorbance band with higher molar absorptivity and narrower shape than the uncomplexed ninhydrin which make it suitable for enhancement using the background correction technique. In this case, the bracketing wavelengths are 475 and 505 nm and the wavelength at the band maximum is 490 nm. While the zinc complex is usually examined using fluorescence [17], the background corrected photography provides another option to the forensic scientist.

Finally, the background correction method can be used with fluorescence analysis, under one of three conditions: a sharp absorbance peak of the analyte masks an excitation or emission peak of an underlying fluorescent substrate, the analyte has a sharp excitation spectrum, or the analyte has a sharp emission spectrum. We have investigated the first and third of these possibilities by examining blood on a fluorescent substrate and by examining Superglue-fumed fingerprints stained with europium fluorophores [18]. In general, use of the background correction method requires identifying compounds with appropriate spectral features to complement the imaging technique.

Some of the limitations in the current instrumentation can be removed by moving to a monochrome camera,

and using image-quality filters or an electronically controllable filter on the camera. These should provide an enhanced image and reduce the time for the process, with the disadvantage of increased cost for the standard forensic laboratory. We are now investigating the use of this equipment.

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