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The non-contact detection and identification of blood stained fingerprints using visible wavelength hyperspectral imaging: Part II effectiveness on a range of substrates

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ABSTRACT

Biological samples, such as blood, are regularly encountered at violent crime scenes and successful identification is critical for criminal investigations. Blood is one of the most commonly encountered fingerprint contaminants and current identification methods involve presumptive tests or wet chemical enhancement. These are destructive however; can affect subsequent DNA sampling; and do not confirm the presence of blood, meaning they are susceptible to false positives.

A novel application of visible wavelength reflectance hyperspectral imaging (HSI) has been used for the non-contact, non-destructive detection and identification of blood stained fingerprints across a range of coloured substrates of varying porosities. The identification of blood was based on the Soret γ band absorption of haemoglobin between 400 nm and 500 nm.

Ridge detail was successfully visualised to the third depletion across light coloured substrates and the stain detected to the tenth depletion on both porous and non-porous substrates. A higher resolution setup for blood stained fingerprints on black tiles, detected ridge detail to the third depletion and the stain to the tenth depletion, demonstrating considerable advancements from previous work. Diluted blood stains at 1500 and 1000 fold dilutions for wet and dry stains respectively were also detected on pig skin as a replica for human skin.
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1. Introduction

Various biological samples are regularly encountered at scenes of violent crime and the successful identification of these is of critical importance in criminal investigations. Of these biological samples, blood is one of the most commonly encountered [1] and is the most commonly observed fingerprint contaminant [2].

The successful identification of blood evidence depends on the ability to conclusively confirm the identity of an unknown substance as blood [3]. Existing wet chemical tests are presumptive only and will indicate on other non-blood substances, resulting in false positives [2]. An ideal method should be highly sensitive to blood and be effective even with blood diluted to latent levels in both stains and fingerprints. Additionally the method should be highly specific to avoid false positives.

One approach is to use non-contact non-destructive optical methods to analyse the sample and visible wavelength hyperspectral imaging has been previously reported for the detection of blood stains using the α and β bands between 500 nm and 600 nm [4–6]. This technique has been identified as a method for the rapid, non-destructive detection of blood stains in a presumptive manner. More recently our research group proposed a new blood stain identification approach using the Soret γ band absorption at 415 nm in haemoglobin for the confirmatory identification of blood [3]. This was shown to provide a higher sensitivity and specificity for the detection and identification of blood stains over previously proposed purely presumptive methods. Additional research by our group explored the effect of time on blood stains and a method for determining the age of blood stains was demonstrated [7,8]. This technique has so far only been applied to blood stains however, highlighting a novel application of visible wavelength hyperspectral imaging for the detection and identification of blood stained fingerprints. One of the key issues involving optical analysis of fingerprints is to ensure that sufficient ridge detail is captured to allow for comparison of crime scene marks against fingerprints from a suspect.

The first part of this study [9] investigated the novel use of hyperspectral imaging for the analysis of blood stained fingerprints on white tiles. The main focus was to establish if ridge detail of a sufficient resolution could be determined, to potentially allow for fingerprint

Abbreviations: DS, Detect stain; DSLR, Digital single lens reflex; HSI, Hyperspectral imaging; PRD, Partial ridge detail; WRD, Whole ridge detail.

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comparison. The outcome of this initial phase was that blood stained fingerprints to a significant number of depletions and dilutions were clearly identified, as well as ridge detail in blood stained fingerprints up to six months old. Blood stained fingerprints were also correctly identified against fingerprints contaminated with a range of red/brown contaminants, with zero false positives. A comparison of the effectiveness of HSI against the visualisation of ridge detail using DSLR photography also demonstrated significant advantages.

In this study we extend the novel application of this technique to the detection and identification of blood stained fingerprints across a range of different coloured substrates and porosities, which are representative of the types of substrates which may be encountered at crime scenes. Further comparison against the visualisation of ridge detail using DSLR photography on these substrates is discussed. Additional novel research is also presented exploring the analysis of blood stains on pig skin using hyperspectral analysis and preliminary findings are discussed following initial improvements to the hyperspectral prototype.

2. Material and methods

2.1. Contamination of digit

Both human and horse blood were used as contaminants in this study. Human blood from a consenting healthy volunteer was used where the blood stains were to be analysed and disposed of within one day (trials 1–3). A sterile lancet (FinePoint, USA) in a Penlet Plus lancing device (LifeScan, USA) was used to pierce the left middle finger. The finger was gently squeezed to encourage blood flow and the resulting blood drops were evenly spread over the ridge detail on the right middle finger. In trial 4 screened horse blood was used. This was deposited into a Petri dish containing a small sponge. The right middle finger was pressed against the sponge to evenly coat the digit and the blood stained fingerprint was then deposited onto the substrate. Standard human and horse blood stained fingerprints were allowed to dry for approximately 1 h before analysis. Wet samples were analysed within 20 min of deposition and dry samples were left to dry for 2 h before analysis to ensure the entire deposited blood stain or fingerprint was dry. All substrates were cleaned with distilled water and thoroughly dried before labelling and fingerprint deposition. All pig skin (Danny's Butchers, Middlesbrough, UK) was flattened before deposition.

2.2. HSI system — Version 1

The HSI system (*Version 1*) used in this study was the same setup detailed in [3,9], consisting of a liquid crystal tuneable filter (LCTF) coupled to a 2.3 megapixel Point Grey camera and a light source for scene illumination. The light source was comprised of two 40 W LEDs; one violet giving an output at 410 nm and one white, giving an output between 450 and 700 nm. Control of the LCTF and image capture was performed using custom developed software written in C++ (Microsoft, USA). Images were captured between 400 nm and 680 nm with spectral sub sampling at 5 nm intervals, resulting in an image cube at 56 wavelengths for each scan. Spectra from the image cube were subsequently analysed using custom routines developed in Visual Studio (Microsoft, USA) and Spyder (Python, USA). The time required to acquire and process an image was approximately 30 s.

2.3. HSI system — Version 2

An improved version of the HSI system (*Version 2*) was created using an upgraded camera and an improved liquid crystal tuneable filter (LCTF). The camera was a 5.5 megapixel CMOS camera (PCO Edge, Germany) coupled to a Varispec CRI liquid crystal tuneable filter. The same lighting setup was used as detailed above in 2.2. Control of the LCTF and image capture was again performed using custom developed software written in C++ (Microsoft, USA), as detailed in 2.2.

2.4. Hyperspectral reflectance image acquisition and pre-processing

The hyperspectral reflectance measurements were made following the method detailed in [3,9]. A reference image (R_0) was obtained using a blank ceramic tile. This image was recorded in a 5 nm series of 56 discrete wavelengths between 400 nm and 680 nm. The sample image (R_s) was recorded at the same wavelengths under the same illumination conditions and integration time settings on the camera. The hyperspectral reflectance image (R) consisted of a data cube of 1920×1200 pixel values at 56 discrete wavelengths. Additional information regarding sample image processing can be found in [3].

2.5. Criteria for the identification of blood stains

The presence of haemoglobin in blood dominates the blood reflectance spectrum in the visible region [7,8]. The spectrum contains a strong narrow absorption at 415 nm called the Soret or γ band with two weaker and broader absorptions between 500 and 600 nm known as the β and α bands [3]. Due to the absorption in the blue part of the visible spectrum, the Soret band is responsible for giving blood its distinctive red colour. Other red substances also absorb in the blue region of the visible spectrum between 400 and 500 nm. However, the width of these absorption features is typically much broader and also not centred at 415 nm. This forms the basis of the methodology to identify and discriminate blood stains from other similarly coloured substances. Further information is detailed in [3]. From the reflectance images obtained, the pixels which satisfied the criterion were marked as black, whilst all other pixels were marked as white. This allowed regions of the image where the blood stained fingerprint was present to be identified, as well as clear distinction of the ridge detail.

2.6. Grading of fingerprints

The same grading method was used as detailed in Part 1 [9] and the trials involving 6 or 12 print depletion series were assessed based on three factors — the furthest deposition where it was possible to detect second level ridge detail (e.g. bifurcations, ridge endings) across the whole of fingerprint (whole ridge detail, WRD), where it was possible to detect some second level ridge detail (partial ridge detail, PRD), and where it was possible to detect the blood stain but no ridge detail at any level could be resolved (detect stain, DS). Whole ridge detail was assigned a score of three, partial ridge detail a score of two, detecting the stain a score of one, and no visualisation a score of zero as shown in Fig. 1.

This grading method was used by the same experienced investigator for all fingerprints to compare the sensitivity of the techniques. The further down the depletion series ridge detail could be detected across the whole fingerprint, the higher the sensitivity of the technique. A single individual was used to grade all fingerprints, so as to remove the additional variable of subjective grading from different individuals. Fingerprints were graded from the on screen images generated by the custom software following hyperspectral analysis and the DSLR images copied from the memory card.

2.7. DSLR setup

The images used in this report were taken using a digital single lens reflex (DSLR) camera mounted on a Kaiser RS1 copy stand. The DSLR was a Canon EOS 700D which was fitted with a Canon Angle Finder C 90° viewfinder with a 1.25–2.5× optical magnification and a Canon TC-80N3 remote control external shutter release to avoid camera motion. Images were taken using two sizes of macro lenses — a 50 mm lens for overview shots of the substrates and a 100 mm lens for high magnification macro shots of individual fingerprints. The 50 mm lens was used as it is recognised as being generally equivalent

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