Chapter 4: Finger mark imaging techniques

4.1 Ultraviolet imaging

1. History

1.1 The existence of ultraviolet (UV) radiation was discovered by Johann Ritter in 1801. He found that emissions beyond the violet region of the electromagnetic spectrum were capable of darkening silver chloride in the same way that visible light at the blue end of the spectrum could. Ritter originally called these rays 'de-oxidising rays' although the term 'chemical rays' was adopted soon after and was in use throughout most of the 1800s. 'Chemical rays' was eventually dropped in favour of the current term 'ultraviolet radiation'.

1.2 By 1931 the forensic applications of UV radiation were already being explored, with UV fluorescence being widely used for document examination and glass identification [1,2]. The results of investigations into the fluorescence of body fluids and drugs under UV illumination were also reported [2].

1.3 In 1970, Ohki carried out an investigation into the potential of UV examination for the detection of latent fingerprints without the need for chemical development [3]. These experiments involved collecting secretions from the human skin by means of gauze wrapped around the hands and feet of several subjects, followed by analysis of these secretions to see if any characteristic UV absorption or fluorescent properties were observed. In these experiments, absorption was observed at 277nm and fluorescence between 300 and 400nm, depending on the solvent used to take the extract. Ohki was able to utilise the UV absorption characteristics of latent fingerprints to capture pictures of untreated latent fingerprints on paper and PVC, those on paper only being visible using a 253nm interference filter but both being visible using a 365nm filter.

1.4 Although the technique was not widely adopted, research continued worldwide to establish the range of surfaces that latent fingerprints could be detected on [4], and to investigate the use of UV image-intensifier viewers for real time observation of latent prints [5,6]. PSDB had demonstrations of some of these early viewing systems. UV-sensitive charge-coupled device (CCD) cameras were also being used for the direct imaging of latent prints by the mid-1990s [7].

1.5 By the 1990s, both long-wave (365nm) and short-wave UV (254nm) imaging techniques were in operational use by the Metropolitan Police [7]. Long-wave UV was found to be useful on glossy magazines, where the fingerprint ridges absorbed and the background fluoresced, and also on stipple surface photographs, where the photographic emulsion absorbed and the fingerprint ridges reflected. Short-wave UV found

application in enhancing marks on patterned backgrounds, where printing absorbed the radiation and the ridges reflected it. Experimental work by the Metropolitan Police group established that the intensity of natural fluorescence in fingerprints was superior in the UV region to that obtained in the visible region [8], with most fluorescence being observed in sebaceous prints. A 266nm neodymium:yttrium aluminium garnet (Nd:YAG) laser was used in these studies, and the level of fluorescence in the fingerprint was observed to decrease with increased exposure time.

1.6 Around the same time, the Rofin company, in conjunction with Israeli researchers, were also developing a short-wave UV-imaging system based on a CCD camera and used this system to image fingerprints in both fluorescence and absorption modes. They also carried out experiments to establish the sensitivity of the system to fluorescence from tyrosine and tryptophan, the amino acids believed to be primarily responsible for the natural UV fluorescence from latent prints [9]. The same group also considered the use of a lower cost imaging system for long-wave UV imaging alone, with the principal applications being the detection of latent fingerprints on smooth surfaces, such as mirrors, and the enhancement of marks developed using superglue without application of fluorescent dyes [10]. The same group also carried out further studies into UV fluorescence [11], showing that for practical casework there were far fewer fluorescent prints present than suggested in the Metropolitan Police study [8], possibly because most prints on paper exhibits are primarily eccrine in character. However, fluorescence was observed in older prints than was suggested in the earlier study. The use of UV imaging for detection of other body fluids was suggested.

1.7 The majority of the imaging systems developed by the Metropolitan Police and the Israel National Police were laboratory-based and not capable of being transported to crime scenes. The US Army Crime Laboratory carried out further experiments with UV image-intensifier systems, which resulted in the commercial production of a scene-portable Reflected Ultraviolet Imaging System (RUVIS) [12]. Several scene-portable RUVIS systems are now available through different manufacturers and reports have been published regarding their practical application to casework [13,14].

1.8 With regard to short-wave UV fluorescence imaging of fingerprints, work has continued in Japan using a tunable laser as the irradiation source and time-resolved imaging to improve fingerprint definition [15]. The equipment used was a laboratory-based imaging system and not suited for use at scenes. The results of the study essentially confirmed the observations of previous researchers regarding optimum excitation wavelengths and the types of fingerprints detected.

1.8 The Home Office Centre for Applied Science and Technology (CAST) has carried out intermittent research into UV imaging. In the mid-1990s a prototype RUVIS system was developed, based on a DEP-Photonis

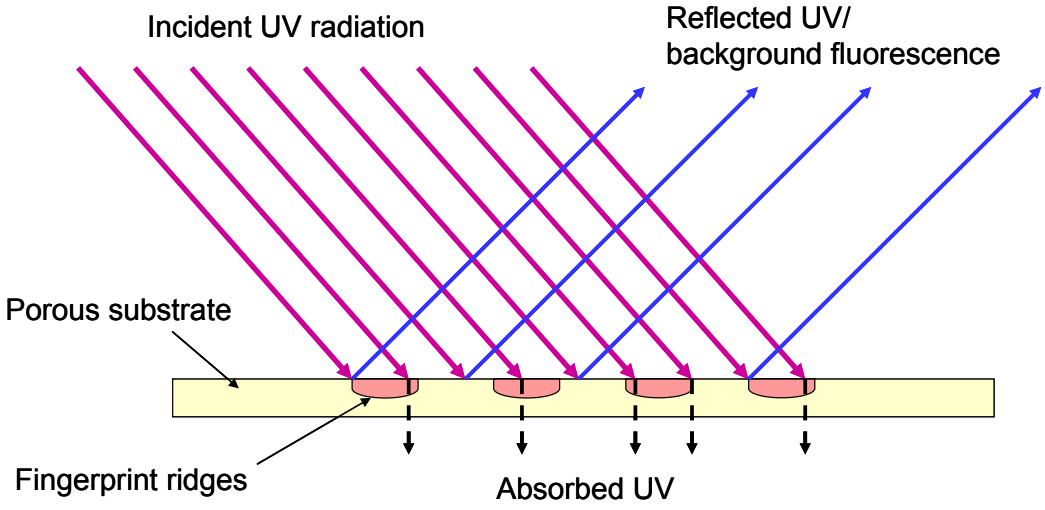
intensifier tube linked to a Nikon 105mm UV lens and a rotatable filter wheel containing a range of different UV filters. This was not pursued any further as a commercial product. A collaborative study was also conducted with the Israeli research group in the late 1990s although this did not result in operational implementation of the process in the UK. Work has also been carried out by CAST to develop safety and best practice guidelines for long-wave UV photography [16], with the focus being on the capture of injury marks and 'smart water' dyed suspects and articles. More recently work has resumed to design and manufacture a laboratory-based UV imaging system based on a UV-sensitive CCD camera (the Alta Apogee U-47 UV) and operated using the software developed for the Integrated Rapid Imaging System (IRIS) digital imaging workstation.

2. Theory

2.1 UV imaging is a broad subject area and there are many processes by which contrast may be obtained between the fingerprint ridges and the background. These include fluorescence, absorption and reflection. Each of these processes is described in greater detail below.

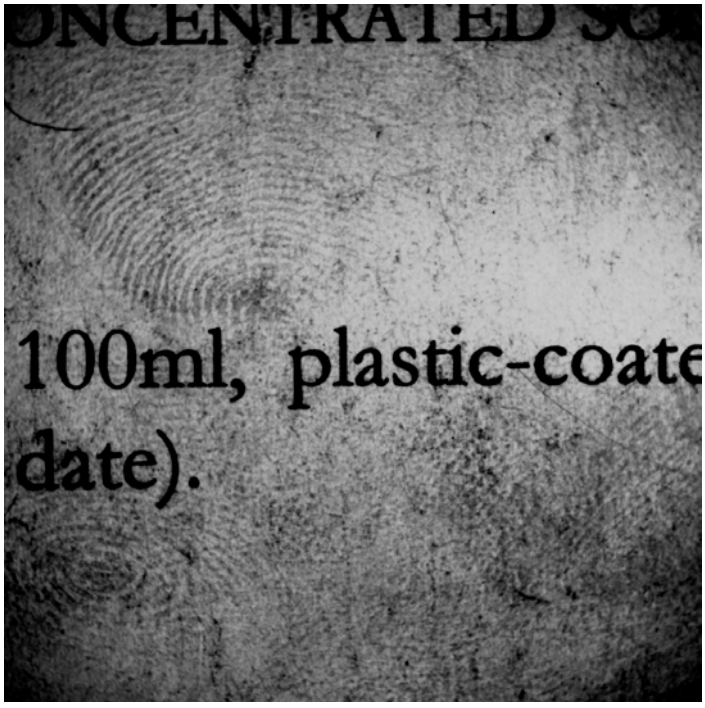
2.2 UV fluorescence. The theory associated with UV fluorescence is identical to that for fluorescence in the visible region of the spectrum. The fingerprint residue is illuminated with short wavelength UV radiation, which promotes electrons within the molecules of certain fingerprint constituents into excited states. These electrons cannot remain in this excited state and drop back to their original electron shell, losing the excess energy by emitting radiation at a longer wavelength (in this case as longer wave UV or into the visible region) than the original excitation. In the case of latent fingerprints, the amino acids tyrosine and tryptophan are believed to contribute most to this fluorescence. UV fluorescence is more applicable to the detection and imaging of latent fingerprints on porous surfaces than to detection of latent fingerprints on non-porous surfaces. However, UV fluorescence is more often used for the enhancement of marks developed using superglue and a range of UV fluorescent dyes are commercially available for this purpose.

2.3 UV absorption. It is known that fingerprint residues absorb strongly at 277nm [3] , primarily due to absorption by fatty acids, and in cases where fingerprints are deposited on surfaces that either fluoresce or reflect UV this phenomenon may be sufficient to provide contrast between fingerprint ridges and the background. This is shown schematically in the figure below.



Schematic diagram showing how ridge contrast of latent marks can be obtained by ultraviolet reflection/absorption.

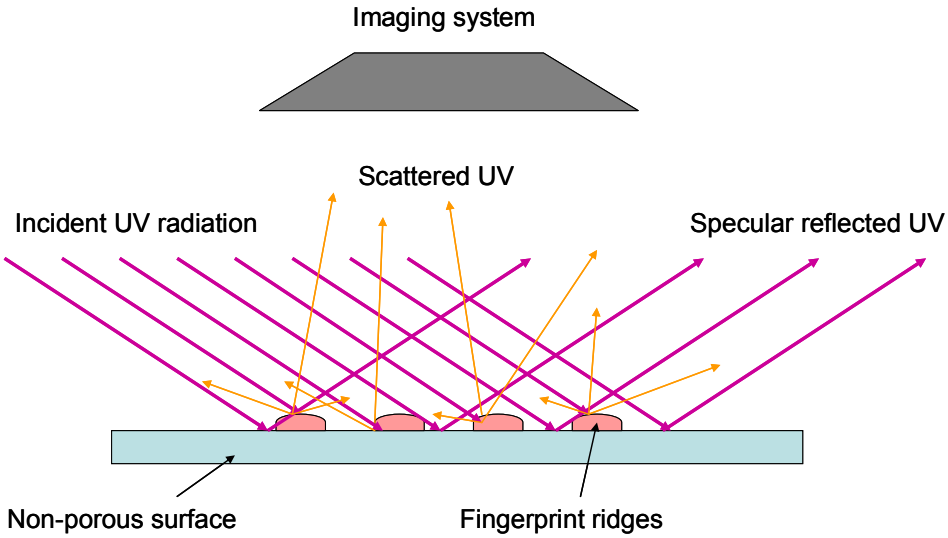
2.4 UV absorption is most applicable to the detection of fingerprints on porous surfaces, in particular on white paper, where optical brighteners fluoresce under UV radiation and provide a stronger contrast with the absorbing fingerprint ridges.



Latent fingerprints detected on glossy paper by reflected short-wave ultraviolet imaging.

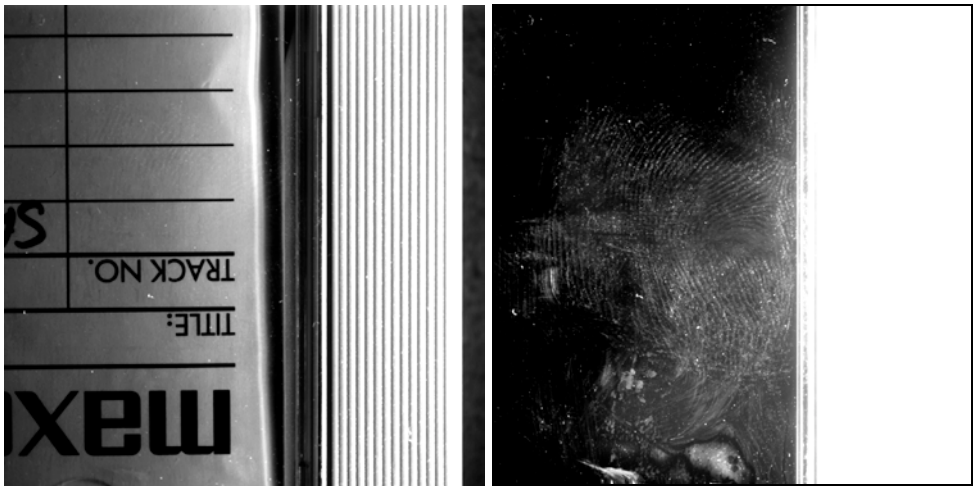
2.5 UV reflection. Reflected UV provides contrast between the fingerprint ridges and the background by means of a greater reflection or scatter from the fingerprint ridges than from the background. This may be due to

the fact the background absorbs UV more strongly than the fingerprint deposits, or by the fingerprint residues being rougher in texture than the background and scattering more UV radiation towards the detection system. This effect is more pronounced in the UV region of the spectrum because the wavelength of the radiation is of a similar scale to the height of the fingerprint ridges, and hence is scattered more strongly than light in the visible region. This is shown schematically below. A short-wave UV band-pass filter may be used in front of the camera to block fluorescence and any reflected visible light emitted by the light source.



Schematic diagram showing how ridge contrast of latent and superglue treated marks can be obtained by ultraviolet reflection/scattering.

2.6 UV reflection is most useful for the detection of latent fingerprints on smooth surfaces, and for the enhancement of marks developed using superglue, where the noodle-like structure of the developed mark scatters strongly.



a) b)

Latent fingerprint on CD case imaged using reflected short-wave ultraviolet a) no filter and b) short-wave ultraviolet band-pass filter.

3. CAST processes

3.1 CAST does not currently (up to 2011) recommend the routine use of short-wave UV imaging for fingerprint imaging because of the health and safety issues associated with short-wave (UV-C) radiation. However, provided that personnel are suitably trained in both UV safety and fluorescence examination, and appropriate precautions are taken in terms of eye and skin protection, there is no reason why UV imaging should not be carried out in a laboratory or at a crime scene.

3.2 Long-wave UV imaging is provided as an option on the IRIS workstation, using either a 365nm fluorescent bulb or the 340–413nm excitation band of the Quaser 2000. IRIS is fitted with a 415nm long-pass (Schott GG435) viewing and camera filter, and will detect fingerprints fluorescing under these illumination conditions. Skin protection (e.g. a pair of latex gloves) is recommended when using the long-wave UV imaging function.

4. Critical issues

4.1 All wavelengths of UV radiation are capable of causing damage to skin and eyes, and personnel using the process should ensure that they are fully trained and aware of the health and safety issues associated with it. Appropriate protective clothing must be worn.

4.2 Exposure to UV radiation (particularly UV-C) will cause progressive damage to DNA and this must be taken into account if it is intended to recover DNA subsequently from the exhibit.

5. Application

5.1 Suitable surfaces: In reflection mode, UV imaging is most appropriate for use on smooth, non-porous surfaces, where the scattering from the ridges is greater than the scattering from the background texture. It is particularly effective on glass where the glass strongly absorbs UV, giving greater contrast between scattering from the ridges and the background. It is also effective on glossy paper surfaces, where fingerprint deposits absorb and the paper surface reflects. In fluorescence mode, UV imaging is capable of detecting fingerprints on all types of surface where UV-fluorescent contaminants are present.

5.2 The main applications of short-wave UV imaging are in the detection and capture of latent fingerprints prior to the application of any chemical treatment. Fingerprints can be detected on both porous and non-porous surfaces by the range of processes outlined above, typically using equipment such as RUVIS for a speculative search of a scene or article and then using specialist equipment to capture marks at the high

resolution required. The advantages of using this technique prior to chemical treatment are that it is non-contact and therefore non-destructive to fingerprints (although if exposure is more than a few minutes it is detrimental to DNA) and that some of the marks revealed will be in the contaminant, and will never be developed by any chemical process. As mentioned above, short-wave UV is destructive to DNA and the process should not be used if DNA recovery is being considered.

5.3 Long-wave UV imaging is more suited to searching for traces of body fluids, but may be capable of revealing marks in this type of contaminant. Latent marks may be revealed by their fluorescence on thermal receipts when illuminated with long-wave UV.

6. Alternative formulations and processes

6.1 There are no alternative processes used for UV imaging in addition to those outlined in the sections above.

7. Post-treatments

7.1 There are no post-treatments used with UV imaging.

8. Validation and operational experience

8.1 CAST has not conducted an extensive study on the effectiveness of UV imaging in operational work. However, the Metropolitan Police has been using UV examination and imaging on operational work for over 20 years. It has been demonstrated that in several cases UV imaging can reveal marks that are not subsequently developed by chemical treatment. It is believed that many of these marks are in contaminants that will not be targeted by chemical or physical development techniques, and hence UV imaging is a valuable tool for operational work. Studies that have been conducted under the control of HOSDB are outlined below.

8.2 Laboratory validation

8.2.1 CAST has conducted limited studies of the relative effectiveness of UV imaging in comparison with other development techniques because the technique is not widely available and is not currently (2011) recommended as a principal treatment. However, a limited investigation has been carried out to compare UV imaging with fluorescence examination on porous surfaces [17]. This study looked at single fingerprints deposited by 36 different donors on 5 different paper types, with the fingerprints aged for 1 day and 1 week. The results are summarised below.

Paper type	Light source	Number of fingerprints detected	Number of identifiable marks	Number of unique marks
Pukka Pad lined paper	Laser (532nm)	3	1	2
	Laser (577nm)	0	0	0
	UV (254nm)	9	3	8
Niceday A4 printer paper	Laser (532nm)	0	0	0
	Laser (577nm)	0	0	0
	UV (254nm)	3	1	3
Hello Silk semi-glossy paper	Laser (532nm)	19	9	1
	Laser (577nm)	14	7	1
	UV (254nm)	28	18	10
Brown envelope	Laser (532nm)	5	2	1
	Laser (577nm)	6	0	2
	UV (254nm)	3	0	0
White envelope	Laser (532nm)	1	0	1
	Laser (577nm)	0	0	0
	UV (254nm)	4	1	4

Results for one-day-old marks using different light sources.

Paper type	Light source	Number of fingerprints detected	Number of identifiable marks	Number of unique marks
Pukka Pad lined paper	Laser (532nm)	4	2	1
	Laser (577nm)	3	0	0
	UV (254nm)	10	3	7
Niceday A4 printer paper	Laser (532nm)	1	0	1
	Laser (577nm)	0	0	0
	UV (254nm)	3	0	3
Hello Silk semi-glossy paper	Laser (532nm)	24	12	1
	Laser (577nm)	18	10	0
	UV (254nm)	29	15	5
Brown envelope	Laser (532nm)	7	0	1
	Laser (577nm)	10	0	4
	UV (254nm)	0	0	0
White envelope	Laser (532nm)	0	0	0
	Laser (577nm)	1	0	0
	UV (254nm)	3	1	2

Results for one-week-old marks using different light sources.

8.2.2 The results demonstrate that short-wave UV imaging is a highly effective process for detection of untreated fingerprints on glossy papers, but less so on rougher paper types. It can also be seen that short-wave UV imaging does detect marks that are not found by fluorescence examination and is a complementary technique for non-contact examination of porous exhibits in cases where chemical treatment is not possible.

8.2.3 A further study looked at the effectiveness of short-wave UV imaging in detection of latent fingerprints on a wider range of surfaces [18]. In this study a depletion series of ten fingerprints were laid by ten different donors, and the marks graded. Marks were examined in a Digital Enclosed Ultraviolet System (DEUS), custom built by the HOSDB workshops. The light sources used were two 8W 254nm mercury vapour lamps, and the imaging system was an Alta Apogee U47-UV camera with a Resolve Optics 60mm forensic lens. For the glass substrate the experiment was repeated three times to give a total of 300 graded marks. The results of this study are summarised below.

Grade	**Substrate (number of marks assessed), percentage at each grade**				
	Glass (300)	Red painted metal (100)	White ceramic tile (100)	Brown parcel tape (100)	Glossy paper (100)
4	56	6	12	0	7
3	20	24	30	13	7
2	9	10	4	14	7
1	13	18	8	22	21
0	2	42	46	51	58

Results of marks found using ultraviolet imaging on a range of substrates.

8.2.4 It can be seen that the proportion of identifiable marks that are detected by the technique ranges from 13– 76% according to the substrate, demonstrating that the process is relatively effective for a non-contact technique.

8.2.5 A study was also conducted on the effect of changing the illumination wavelength. A series of samples were illuminated with long-, mid- and short-wave UV radiation in the DEUS imaging chamber [18]. Two 8W tubes were used for each wavelength, the tubes being incorporated into the same mountings for each wavelength. These results of examining depletion series of 10 marks from 10 different donors (i.e. a total of 100 marks) are summarised below.

Wavelength	**Number of marks detected using optimum filter**	
	Paper	**Glass**
365nm (UV-A)	1	45
302nm (UV-B)	6	83
254nm (UV-C)	10	98

Results of marks found using ultraviolet imaging at different wavelengths.

8.2.6 The results show the increased effectiveness in fingerprint detection as the wavelength of illumination decreases, and demonstrates why UV-C is preferred if fingerprint detection is the priority.

8.3 Pseudo-operational trials and operational experience

8.3.1 CAST has not conducted any pseudo-operational trials using short- or long-wave UV imaging. The Metropolitan Police routinely uses long-wave UV to search crime scenes, and has recently conducted an analysis of the number of unique marks detected by light source examination, including long-wave UV, white light and laser examination [19]. This demonstrated that light source examination accounted for ~8% of unique marks detected, although the proportion of those that were uniquely identified using long-wave UV was not identified.

8.3.2 The Metropolitan Police also uses short-wave UV imaging under controlled conditions in a laboratory, and there are several documented examples of where it has detected marks not subsequently developed by chemical techniques.

9. References

1. **Rhodes, H. T. F**. (1931) *Some Persons Unknown*. London: John Murray.

2. **Radley, J. A. and Grant, J.** (1954) *Fluorescence Analysis in Ultra-Violet Light*, 4th Edition. New York: D. Van Nostrand Company Inc.

3. **Ohki, H.** (1970) 'Physio-chemical Study of Latent Fingerprint. 1 Ultraviolet Absorption and Fluorescence of Human Epidermal Secretion', *Reports of the National Research Institute of Police Science* (Japanese), vol. 23 (1), pp 33–40.

4. **Qiang, W. G**. (1995) 'Detecting and Enhancing Latent Fingerprints with Short Wave UV Reflection Photography', *Proceedings of the International Symposium on Fingerprint Detection and Identification*, June 26–30, 1995. Israel: Ne'urim.

5. **Saito, N. and Arai, S.** (1972) 'The Detection of Fingerprint by Ultraviolet Ray Television', *Reports of the National Research Institute of Police Science* (Japan) vol. 25 (1), pp 57–58.

6. **Hamamatsu** (1987) 'Fingerprint Detection and Recording with Hamamatsu Intensified Ultraviolet Viewer', *Hamamatsu Application Bulletin*, November 1987.

7. **Creer, K. E.** (1995) 'The Detection and Enhancement of Latent Marks Using Specialised Lighting and Imaging Techniques', *Proceedings of*

the International Symposium on Fingerprint Detection and Identification, June 26–30, 1995. Israel: Ne'urim.

8. **Bramble, S. K., Creer, K. E., Qiang, W. G. and Sheard, B.** (1993) 'Ultraviolet Luminescence from Latent Fingerprints', *Forens. Sci. Int.* vol. 59, pp 3–14.

9. **Fraval, H., Bennett, A. and Springer, E.** (1995) 'UV Detection of Untreated Latent Fingerprints', *Proceedings of the International Symposium on Fingerprint Detection and Identification*, June 26–30, 1995. Israel: Ne'urim.

10. **Springer, E.** (1995) 'Two Techniques for Improving Fingerprint Yield', *Proceedings of the International Symposium on Fingerprint Detection and Identification*, June 26–30, 1995. Israel: Ne'urim.

11. **Nissim, B. Y., Almog, J., Frank, A., Springer, E. and Cantu, A.** (1998) 'Short UV luminescence for forensic applications: Design of a real time observation system for detection of latent fingerprints and body fluids', *J. Forens. Sci* vol. 43 (2), pp 299–304.

12. **German, E. R.** (1995) 'Reflected Ultraviolet Imaging System Applications', *Proceedings of the International Symposium on Fingerprint Detection and Identification*, June 26–30, 1995. Israel: Ne'urim.

13. **Keith, L. V. and Runion, W.** (1998) 'Short-wave UV imaging casework applications', *J. Forens. Ident.*, 48 (5), pp 563–569.

14. **Saferstein, R. and Graf, S. (**2001) 'Evaluation of a reflected UV imaging system for fingerprint detection', *J. Forens. Ident.,* vol. 51 (4), pp 385–393.

15. **Saitoh, N. and Akiba, N.** (2006) 'Ultraviolet fluorescence of fingerprints', *The Scientific World Journal*, 6, pp 691–699.

16. **PSDB** (2001) *Revised Guidelines for the Use of Low Powered Ultraviolet Light Sources for the Detection of Fluorescent Dyes on Articles and Suspects*, PSDB Note, July. London: Home Office.

17. **Bleay, S. M.** (2009) Unpublished project work. London: Home Office.

18. **Bannister, M.** (2009) *The Use of Ultra Violet Imaging in the Detection of Forensic Evidence*, HOSDB Student Placement Report, June.

19. **Jakes, P., Bleay S., Marsh N., Sears V. and Watkinson, T.** (2011) 'A comparison of the effectiveness of light sources and chemical processes at developing latent fingermarks', draft paper, *in preparation.*

4.2 Infra-red imaging

1. History

1.1 The existence of infra-red (IR) radiation was discovered in 1800 by William Herschel, building on Newton's observation that sunlight could be separated into different colours by refraction through a glass prism. Herschel was investigating the theory that different colours could contain different levels of heat, and confirmed this by placing thermometers in different colour ranges of the spectrum. Herschel observed that the measured temperature increased from the violet to the red end of the spectrum, but made the additional observation that the measured temperature continued to increase beyond the red portion of the spectrum indicating that non-visible radiation was present. This radiation was termed 'calorific rays' by Herschel, with the term 'infra-red' being adopted in the late 19th century.

1.2 The practical applications of IR radiation were limited until the development of the first detector materials towards the end of World War I. Military imaging applications continued to be the main driver for the development of IR detectors and imaging systems for several decades, with the first IR imaging devices developed in the 1940s.

1.3 Forensic applications of IR imaging did not begin to be widely explored until the advent of detectors linked to video displays, allowing live imaging in the IR region of the spectrum. Specialised IR photography could be carried out using conventional cameras with IR sensitive film [1], but this was often speculative, carried out under the assumption that a feature of interest would be present. With live imaging capability, investigators could see whether there were any IR reflection or fluorescence effects occurring and subsequent photography could be targeted appropriately. Some early experiments were carried out in the Metropolitan Police Forensic Science laboratory and elsewhere using first generation military image converter tubes utilising S1 photocathodes and subsequently S20 photocathodes.

1.4 The principal application of IR imaging in forensic science was in document examination and from the 1950s onwards various researchers [2-5] used IR sensitive vidicons to investigate the potential of reflected IR and IR fluorescence for applications such as detection of forgeries, revelation of erased writing and ink comparison. As the cost of image converters and IR detectors reduced, bench-top document examination equipment became available in the late 1970s/early 1980s, enabling routine examination of documents in forensic laboratories. IR imaging systems utilising vidicons based on those developed in the Birmingham Forensic Science laboratory [4] were commercialised by Foster and Freeman and marketed as the Video Spectral Comparator (VSC).

1.5 In addition to document examination, IR photography was also found to be a valuable tool for the imaging of blood spatter patterns on surfaces

appearing dark under visible light [6]. Similarly, IR photography has also been used in the imaging of injuries (such as bruising) on skin [7].

1.6 The potential use of IR imaging for visualisation of fingerprints was being considered in the 1970s. Wilkinson [8] makes an early reference to the use of IR microscopy to enhance a powdered mark (IR opaque) on a dark green bottle (IR translucent) and a US Patent issued around the same time [9] makes specific reference to the IR responsive nature of a fingerprint powder. This does not appear to have resulted in a significant increase in the use of IR imaging for fingerprint applications. However, the Metropolitan Police was using reflected IR for photography of marks revealed using physical developer in the mid-1980s [10]. The same group subsequently reported the use of IR long-pass filters to detect IR fluorescence from latent fingerprints illuminated with an argon ion laser at 514.5nm [11]. In the early 1980s PSDB conducted trials at the laboratories of STC Harlow on the use of a scanning thermal imaging microscope for the detection of finger marks on difficult surfaces such as adhesive tape and some metals, hoping to exploit differences in emissivity. This was not pursued at the time due to the limited resolution of the systems available and low contrast observed.

1.7 Later research using a live capture digital imaging system demonstrated that in addition to IR fluorescence of latent prints, existing fingerprint reagents such as basic violet 3 (Gentian Violet) exhibited some fluorescence in the IR region of the spectrum. This fluorescence could be used to aid visualisation of the developed mark [12].

1.8 Subsequent work by the Home Office Scientific Development Branch (HOSDB) [13] demonstrated that IR reflection was an effective technique in suppressing background patterns when metallic or inorganic development reagents (e.g. vacuum metal deposition, powders, powder suspensions and physical developer) were used, although marks developed using organic reagents such as ninhydrin became transparent and could not be seen in the IR. HOSDB also demonstrated that IR fluorescence can be observed for the protein dyes acid black 1 and acid violet 17 [14]. Although IR fluorescence is observed for the pure acid violet 17 dye, much stronger fluorescence is seen for batches of acid violet 17 mixed with dextrin and this may offer a route for producing IR fluorescent reagents in the future.

1.9 All of the above forensic applications utilise the near IR region of the spectrum where the interactions of the incident radiation with the fingerprint residue and the substrate are very similar to those occurring in the visible region. Further into the IR region the incident radiation can promote molecular vibrations, such as bond stretching and rotation, and characteristic absorption peaks associated with these motions can be used to characterise chemical species present in the fingerprint. This approach was applied in a study to compare fingerprint residues of males, females and children, investigating compositional differences between these groups and between eccrine and sebaceous deposits

[15]. This study used spectromicroscopy and focused on a small portion of an individual ridge. A later study looked at the same technique to detect and identify particles trapped in the fingerprint ridges, such as illicit drugs [16].

1.10 More recently the use of the short- and mid-wave IR regions of the spectrum has been considered for the imaging of fingerprints, using wavelengths where absorption mechanisms characteristic of chemical species in the fingerprint ridges occur. The systems used to image fingerprints in this way are currently (in 2011) highly specialised pieces of equipment more suited to research than operational work, mostly using Fourier Transform IR (FTIR) spectroscopy techniques. A FTIR focal plane array detector has been used to scan a fingerprint on an Australian banknote in a series of lines, stitching these together to form the final image [17]. Other researchers have used FTIR imaging to detect both latent and treated fingerprints on a range of porous and non-porous surfaces [18]. In an alternative approach researchers have used arrays of FTIR sensors in the attenuated total reflection (ATR) mode [19], which significantly reduced the time taken to produce the image, but there is still the potential to increase the size of the array and reduce the imaging time for the whole area of the fingerprint. The limitation of this approach has been that the sample bearing the fingerprint needs to be flat and in intimate contact with the detector. This limits the type of exhibit that can be examined using ATR-FTIR equipment, but to overcome this limitation the lifting of marks and other forensic evidence from exhibits using gel lifters and tape has been investigated [20,21]. This technique offers the potential to bring marks back from a crime scene for subsequent laboratory analysis.

1.11 Other regions of the IR spectrum may also offer potential for fingerprint detection, and one approach that has been proposed is to pass humidified air over latent fingerprints and utilise an IR thermography camera to detect temperature differences between the fingerprint ridges and the substrate [22]. This does not appear to have been progressed further in recent years.

2. Theory

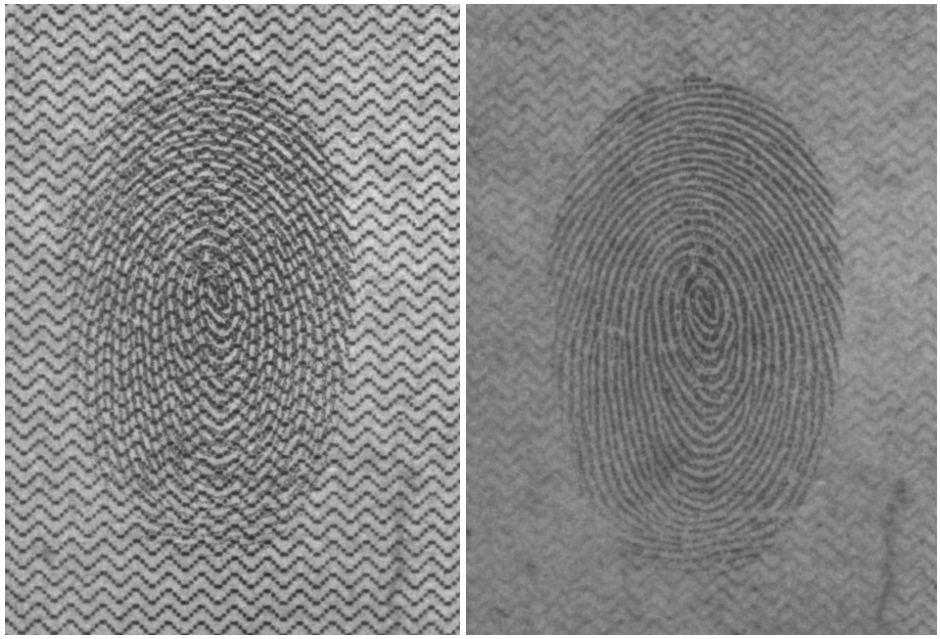
2.1 IR imaging is a broad subject area and there are many processes by which contrast may be obtained between the fingerprint ridges and the background. In the near IR regions these include fluorescence, absorption and reflection. At longer IR wavelengths there are other mechanisms that can be used to distinguish fingerprints, including IR absorption characteristics associated with chemical species present in the fingerprint but not in the substrate, and thermography using differences in emissivity between the fingerprint and the substrate. Each of these processes are described in greater detail below.

2.2 Near IR (700–1,100nm)

2.2.1 In this region of the IR spectrum, the mechanisms used for fingerprint visualisation are essentially the same as those used in the visible and ultraviolet (UV) regions, namely fluorescence and absorption/reflection. The principal difference from imaging in the visible region is that many of the organic pigments used in printing inks are IR transparent, and surfaces that appear highly patterned and/or coloured under 'daylight' conditions in the visible spectrum may appear devoid of printing when viewed in the near IR. This can be a significant advantage when trying to resolve minutiae in fingerprints developed on articles like banknotes.

2.2.2 It has already been established that some fingerprint reagents do have some fluorescence in the IR when illuminated with green/yellow and yellow light, most notably basic violet 3 and acid violet 17 (although much of the emission of basic violet 3 is actually in the red spectral region). However, the use of longer wavelength illumination such as orange, red and IR, and the resultant fluorescence from existing reagents has not yet been extensively explored. The potential to develop IR fluorescent dyes and reagents for fingerprint detection clearly exists and could be exploited in future. Preliminary investigations have indicated that there may be some constituents of latent fingerprints that have fluorescence in the near IR, but optimum illumination conditions have not yet been identified.

2.2.3 For fingerprint imaging using IR reflectivity, a light source emitting in the near IR is required. As stated above, many inks used for printing are IR transparent and highly patterned surfaces may be suppressed. To date, it does not seem that latent fingerprints can be detected in this way. It has not yet been established whether there are any fingerprint constituents that have characteristic absorption mechanisms in this region, but the background fluorescence of most surfaces is low and the contrast between the substrate and ridges is insufficient for fingerprint visualisation. However, it is possible to image some developed fingerprints in IR reflection mode. Many organic reagents and dyes, including ninhydrin, solvent black 3 and superglue, are transparent in this region of the IR spectrum and developed marks are not visible. Those developed using inorganic or metallic processes, including vacuum metal deposition, powders and powder suspensions, either absorb or scatter IR more than the background and developed marks remain visible when imaged in the IR.



a) b)

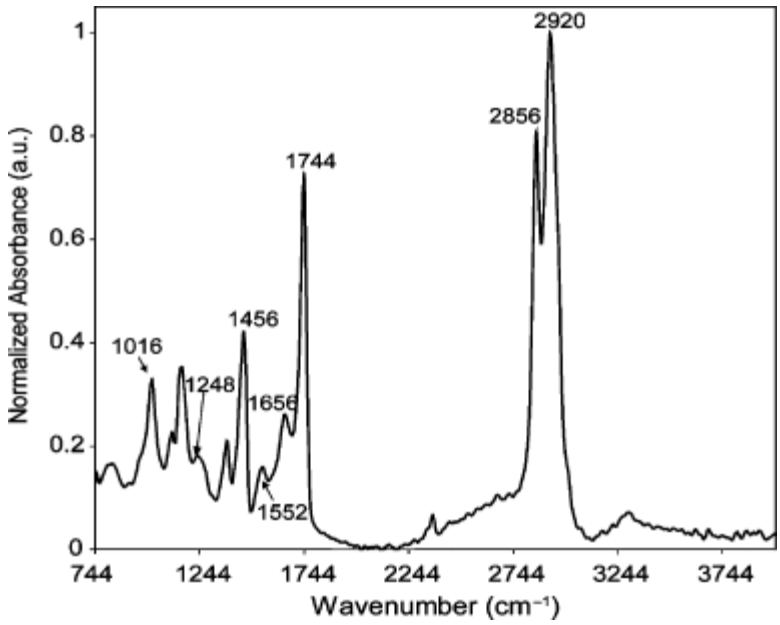
Images of fingerprint developed using physical developer on patterned background a) imaged under tungsten illumination and b) imaged under tungsten illumination using an infra-red long-pass filter (Schott glass RG780).

2.3 Short-wave IR (1,100–1,700nm)

2.3.1 This region of the IR spectrum has not yet been extensively studied for the detection of fingerprints and there is no established process for fingerprint detection. However, there are some known processes, such as water absorption bands at around 1,300nm, that could be exploited in future.

2.4 Medium-wave–long-wave IR (1,700–25,000nm)

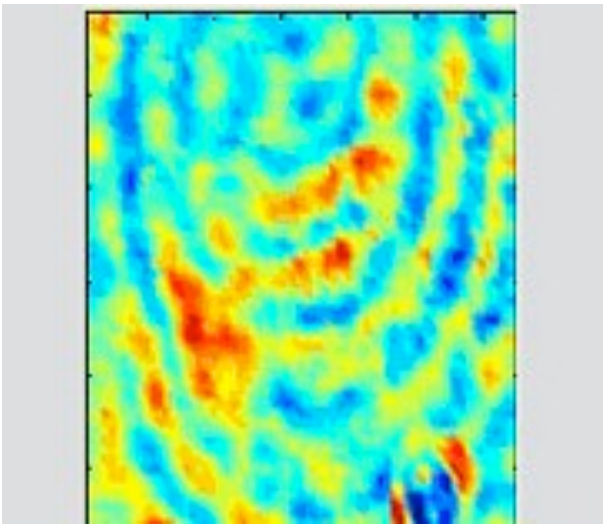
2.4.1 Further into the IR spectrum, many organic compounds have characteristic absorption peaks associated with vibration of organic sidegroups or stretching of chemical bonds. This chemical specificity can be utilised to discriminate different compounds using techniques such as FTIR spectroscopic imaging.



Wavenumber (cm^{-1})	**Assignment**
1,016	Asymmetric O–C–C stretch, ester
1,248	Asymmetric C–C–O stretch, ester (C bonded to the O included in the carbonyl)
1,456	CH_2 scissors
1,552	N–H bend combined with C–N stretch, protein amide II feature
1,656	C=O stretch, protein amide I feature
1,744	C=O stretch, saturated ester
2,856	Methylene C–H stretch
2,920	Methyl C–H stretch

Fourier Transform infra-red spectrum from fingerprint residue and molecular motions associated with peaks [18]

2.4.2 Researchers have begun to investigate the potential of this for fingerprint detection. It is possible to use a peak wavelength characteristic of a particular constituent of the fingerprint residue or fingerprint development reagent (but not present in the substrate) to obtain an image giving enhanced contrast between the fingerprint and the background.



Attenuated total reflection-Fourier Transform infra-red image of a fingerprint, showing distribution of lipid components.

2.4.3 This has been successfully demonstrated for fingerprints developed using cyanoacrylate fuming on the highly patterned background of an Australian banknote. The technique may also be able to detect the presence of other characteristic compounds (e.g. drugs, explosives) in fingerprint residues, giving investigators additional information about the person depositing the fingerprint.

2.4.4 At longer wavelengths, other mechanisms can be utilised to image fingerprints. IR imaging systems in this region can be used in non-destructive evaluation applications, such as thermography. There is the possibility of obtaining a contrast between fingerprint ridges and the substrate by exploiting differences in emissivity or differences in thermal conductivity between the two materials. By applying a pulse of heat or humidified air to the region of interest and observing the response of the surface using a thermal camera, it may be possible to resolve fingerprint ridges. This approach is routinely used for defect detection in aerospace materials and has been considered as a fingerprint detection technique, although a practical system has not yet been produced.

3. CAST processes

3.1 IR imaging is not currently (2011) recommended in the *Manual of Fingerprint Development Techniques* 2nd edition because it does not reveal fingerprints in its own right but can aid the visualisation of fingerprints developed using other processes, in particular physical developer. It is likely to be included as a specialist imaging process in the next edition of the manual.

3.2 IR imaging is recommended in the recent HOSDB newsletter on arson [23], where it has been demonstrated that IR imaging can reveal fingerprints treated with physical developer on charred paper exhibits.

Because IR imaging is an essentially non-destructive technique it can be inserted at appropriate stages of any sequential treatment without detriment to subsequent treatments.

3.3 The procedure currently (2011) recommended is to utilise a digital imaging system without an IR blocking filter bonded to the chip. Previously this option was only available in scientific grade, machine vision cameras, but digital single lens reflex (SLR) cameras are now becoming available for forensic imaging applications that are built without UV/IR blocking filters over the sensor. For IR reflection imaging, a light source emitting in the near IR is required. Standard halogen bulbs are appropriate for this purpose. To view the reflected IR radiation and block the visible region of the spectrum, IR cut-on filters are used in front of the camera. A range of Schott glass filters are available giving cut-on wavelengths between 645 and 1000nm. Although the lower wavelength filters do have some use in document examination, those of most use in suppression of patterned/coloured backgrounds and charred substrates in fingerprint imaging are RG715, RG780, RG850 and RG1000.

3.4 The same range of camera filters can be used when imaging in IR fluorescence. However, the light sources and fingerprint development reagents for this application have not yet been optimised.

4. Critical issues

4.1 For near IR imaging to be effective, imaging devices that are sensitive in the IR region of the spectrum must be used. Conventional charge coupled devices (CCD) and complemetary metal oxide semiconductor (CMOS) sensors used in digital cameras are not sensitive in this region because they usually have an UV/IR blocking filter bonded to them. Specialist models of camera are becoming available for IR imaging with this blocking filter removed.

4.2 An appropriate light source must also be used. For IR reflection imaging the light source must output in the near-IR region. Tungsten lamps are suitable for this purpose, fluorescent tubes and light emitting diodes (LEDs), unless specifically produced for IR emission, are not. The most appropriate wavelengths for exciting IR fluorescence are not yet known.

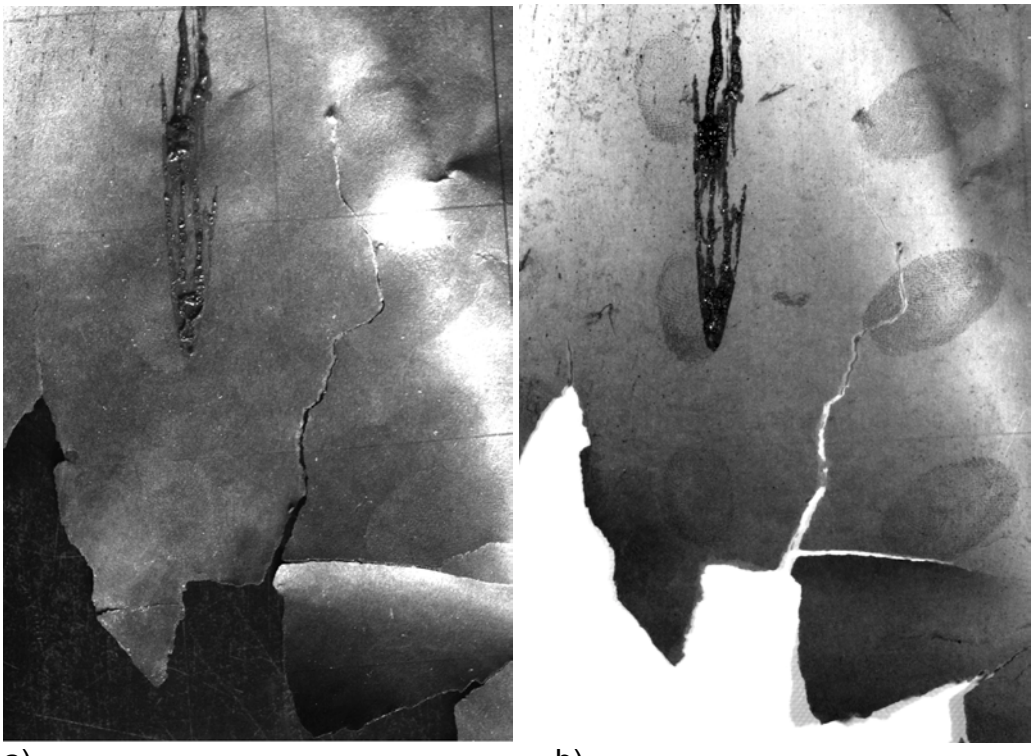
5. Application

5.1 Suitable surfaces: Reflected IR imaging is suitable for use on any coloured, patterned surface provided that the fingerprints present have been developed using a process that leaves metallic or inorganic material on the fingerprint ridges (e.g. powders, vacuum metal deposition, powder suspensions). The fingerprints then remain visible in the IR region of the spectrum and organic dyes and inks are typically

transparent. This has been found to be effective on printed paper, fabrics and printed plastic bags.

5.2 The principal application for IR imaging has been in the suppression of patterned backgrounds on porous substrates where marks have been developed using physical developer. This is of particular benefit on articles such as banknotes, where the printing is multicoloured and patterned. Although regular background patterns can be removed using digital techniques such as fast Fourier transforms, in many regions of banknotes the pattern is not regular and this approach cannot be used. The most commonly used technique for porous surfaces, ninhydrin, produces marks of a similar colour to the £20 note and makes imaging of features difficult. In these cases, using physical developer followed by IR imaging can produce fingerprints that cannot be visualised by other techniques.

5.3 The other application where IR imaging has been proven to be of benefit is on charred articles, again where physical developer has first been used to develop any marks present [23].



a) b)

Photograph of fingerprints developed using physical developer on charred paper a) viewed under tungsten illumination and b) viewed under tungsten illumination using infra-red long-pass filter (Schott glass RG780).

6. Alternative formulations and processes

6.1 There are many regions of the IR spectrum that can be utilised for IR imaging of fingerprints, and the different techniques for imaging fingerprints have been described in the preceding sections.

7. Post-treatments

7.1 There are no post-treatments used with IR imaging.

8. Validation and operational experience

8.1 IR imaging is used as a non-destructive post-treatment to aid in the visualisation of marks developed using other processes and therefore an extensive validation study has not been conducted. Studies have been carried out on a range of UK and European banknotes (one of the principal surfaces where IR imaging could give benefits) to demonstrate which elements of the printed background drop out under IR imaging conditions. A further small-scale study has been carried out by CAST to demonstrate which fingerprint development processes give marks that are still visible when imaged in the near IR [13].

8.2 There are known operational cases where police forces have utilised IR imaging to suppress backgrounds on exhibits where marks have been developed using physical developer. One police force treated a batch of £20 notes with ninhydrin and although several marks were developed these were in patterned regions where it was not possible to resolve minutiae. CAST recommended re-treating the exhibits with physical developer followed by IR imaging and several identifiable marks were produced.

8.3 Another force carrying out a cold case review treated a 25-year-old postal order that had been wetted with physical developer. A mark was developed but some minutiae were obscured by printing. IR imaging successfully suppressed the printing and revealed some additional minutiae. However, there was still insufficient detail for an identification.

9. References

1. **Von Bremen, U.** (1967) ‘Systematic application of specialised photographic techniques’, *J. Crim. Law Criminol. Police Sci.*, 58 (3), pp 410–413.

2. **Hilton, O.** (1962) ‘Traced forgeries and infra red photography’, *Int. Crim. Police Rev.,* 159, pp 195–197.

3. **Ellen, D. M. and Creer, K.** (1970) 'Infra-red luminescence in the examination of documents', *J. Forens. Sci. Soc.,* vol. 10, pp 159–164.

4. **Hardcastle, R. A. and Hall, M. G.** (1978) 'A technique for the enhancement of the infra-red luminescence of inks', *J. Forens. Sci. Soc.*, vol. 18, pp 53–55.

5. **Cantu, A. A. and Prough, R. S.** (1988) 'Some special observations of infra-red luminescence', *J. Forens. Sci.* vol. 33, pp 638–647.

6. **Raymond, M. A. and Hall, R. L.** (1986) 'An interesting application of infra-red reflection photography to blood splash pattern interpretation', *Forens. Sci. Int.,* vol. 31, pp 189–194.

7. **Wright, F. D.** (1998) 'Photography in bite mark and patterned injury documentation – part 2: A case study', *J. Forens. Sci.* vol. 43 (4), pp 881–887.

8. **Wilkinson, R. D.** (1979) 'The use of infrared microscopy in detecting latent fingerprints', *Ident. News*, August, pp 10–11.

9. **Worsham, R. and Jenkins, J.** (1980) 'Infra-red responsive fingerprint composition and method of making', US Patent 4,226,740, October 7.

10. **Pearson, E. F., Creer, K., Brennan, J. S., Newson, N. E. and Pounds, C. A.** (1984) 'An advanced technology unit for the detection of fingerprints', *Proceedings of the E.E.C International Fingerprint Conference*, London, 27–30 November 1984. London:

11. **Creer, K. E. and Brennan, J. S.** (1987)'The work of the serious crime unit', *Proceedings of the International Forensic Symposium on Latent Prints*, pp 91–99, Virginia, 7–10 July 1987. Virginia, USA: FBI Academy, Quantico.

12. **Bramble, S. K., Cantu, A. A., Ramotowski, R. S. and Brennan, J. S.** (2000) 'Deep red to near infrared (NIR) fluorescence of Gentian Violet-treated latent prints', *J. Forens. Ident.*, vol. 50 (1), pp 33–49.

13. **Bleay, S. M. and Kent, T.** (2005) 'The use of infra-red filters to remove background patterns in fingerprint imaging', *Fingerprint Whorld*, vol. 31 (122), pp 225–238.

14. **Bandey, H., Bleay, S., Bowman, V., Fitzgerald, L., Gibson, A., Hart, A. and Sears, V.** (2006) 'Fingerprint imaging across EM spectrum', *Imaging Science J.,* vol. 54, pp 211–219.

15. **Williams, D. K., Schwartz, R. L. and Bartick, E. G.** (2004) 'Analysis of latent fingerprint deposits by infrared microspectrometry', *Appl. Spectrosc.*, 58, pp 313–316.

16. **Grant, A., Wilkinson, T. J., Holman, D. R. and Martin, M. C.** (2005) 'Identification of recently handled materials by analysis of latent human fingerprints using infrared spectromicroscopy', *Appl. Spectrosc.,* 59 (9), pp 1182–1187.

17. **Tahtouh, M., Kalman, J. R., Roux, C., Lennard, C. and Reedy, B. J.** (2005) 'The detection and enhancement of latent fingermarks using infrared chemical imaging', *J. Forens. Sci.* vol. 50 (1), pp 1–9.

18. **Crane, N. J., Bartick, E. G., Perlman, R. S. and Huffman, S.** (2007) 'Infrared spectroscopic imaging for non-invasive detection of latent fingerprints', *J. Forens. Sci.,* vol. 52 (1), pp 48–53.

19. **Chan, K. L. A. and Kazarian, S. G.** (2006) 'Detection of trace materials with Fourier Transform infrared spectroscopy using a multi-channel detector', *Anal*., 131, pp 126–131.

20. **Ricci, C., Chan, K. L. A. and Kazarian, S. G.** (2006) 'Combining the tape-lift method and Fourier transform infrared spectroscopic imaging for forensic applications', *Appl. Spectrosc.,* 60 (9), pp 1013–1021.

21. **Ricci, C., Bleay, S. M. and Kazarian, S. G.** (2007) 'Spectroscopic imaging of latent fingermarks collected with the aid of a gelatine lifter', *Anal. Chem.,* 79 (15), pp 5771–5776.

22. **Bodmann, B.** (2001) 'Infrared-optical process for the visualization of latent fingerprints' *Presentation at International Fingerprint Research Group,* Weisbaden, 14–17 August 2001

23. **Bleay, S. M., Bradshaw, G. and Moore, J. E. (**2006) *HOSDB Fingerprint Development and Imaging Newsletter: Special Edition Arson*, HOSDB Publication No. 26/06, April. London: Home Office.

4.3 Multispectral imaging and monochromatic illumination

1. History

1.1 Multispectral imaging is a technology originally developed for aerial photography, and describes a system capable of simultaneously capturing spectral as well as spatial information. The spectral information can be used to distinguish between areas of nominally similar appearance, e.g. identifying different types of crop or vegetation by the differences between their reflected light spectra. More recently, the technique has been applied to other scientific disciplines, in particular medical imaging. In this application, the spectral information captured by multispectral imaging has been used to differentiate between different types of cell/tissue stained with coloured or fluorescent markers. Multiple stains can be used on a single sample and multispectral imaging used to identify the distribution of each in turn.

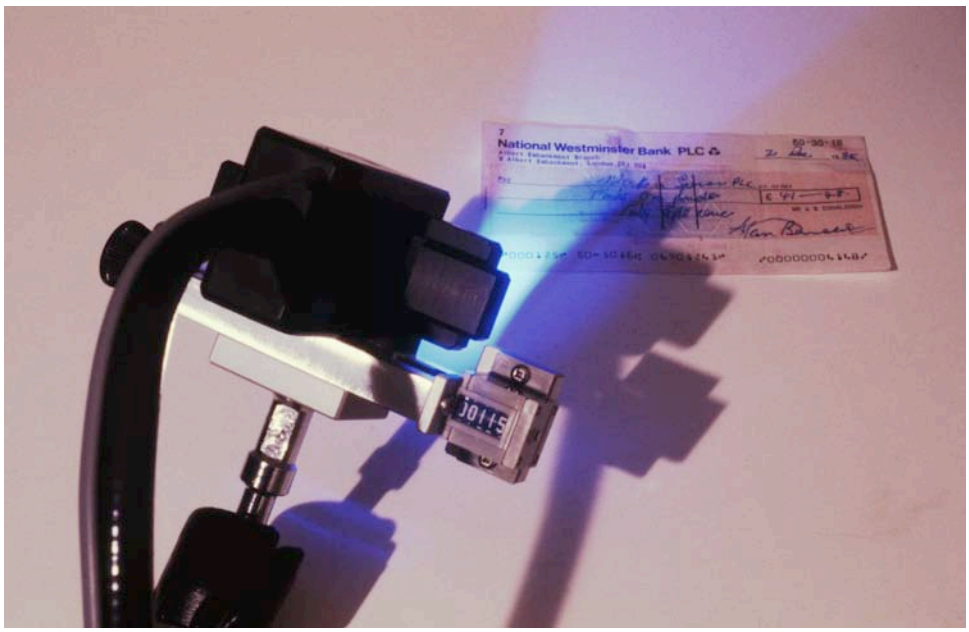
1.2 The potential of the technique for forensic applications became recognised in the late 1990s and Exline *et al* [1] demonstrated that chemically treated fingerprints could be imaged in both absorption and fluorescence modes using multispectral imaging systems, and that the improved spectral resolution obtained revealed more ridge detail than conventional imaging routes. In some cases, latent untreated fingerprints could be detected on coloured paper by multispectral imaging alone. Later studies by the same group demonstrated that the technique could be applied to a wide range of treated fingerprints, and faint ninhydrin marks in particular could be significantly enhanced by this method [2].

1.3 Initial forensic studies utilised multispectral imaging systems operating in the visible/near infra-red (IR) regions of the spectrum although later studies [3,4,5] demonstrated that multispectral imaging systems operating further into the IR region could also be used to resolve fingerprints, in this case using specific chemical vibrations from species present in fingerprint ridges to resolve the print against a patterned background.

1.4 Subsequent studies using both visible and IR multispectral imaging demonstrated that the technique could also be applied to document examination, including ink discrimination, paint analysis, detection of gunshot residue and fibre analysis [6,7,8].

1.5 The Home Office Scientific Development Branch (HOSDB) purchased a multispectral imaging system in 2006 and initially confirmed the results of the Australian researchers for a range of different fingerprint development techniques [9]. The technique has since been applied to some operational cases, demonstrating that fingerprints can be successfully resolved against coloured/patterned backgrounds by means of their characteristic spectral response.

1.6 Monochromatic illumination is closely related to multispectral imaging in terms of using spectral differences to differentiate between chemically treated fingerprints and similarly coloured backgrounds. Monochromators function by splitting white light into narrow spectral bands, and may utilise prisms, variable diffraction gratings or variable interference filters to achieve this. In the fingerprint imaging application, a monochromator is used in conjunction with a white light source to illuminate an exhibit with a narrow portion of the visible spectrum. By choosing a region of the spectrum that matches and suppresses reflected light from the background, fingerprints may be resolved. HOSDB first investigated this approach for the imaging of fingerprints developed using ninhydrin against the patterned backgrounds of cheques in the late 1980s [10] and developed the Quaserchrome monochromator accessory for use with the Quaser 100 and Quaser 40 at about the same time. More recently, monochromators have been provided as an integral part of the Integrated Rapid Imaging System (IRIS) workstation [11] developed and manufactured by HOSDB.

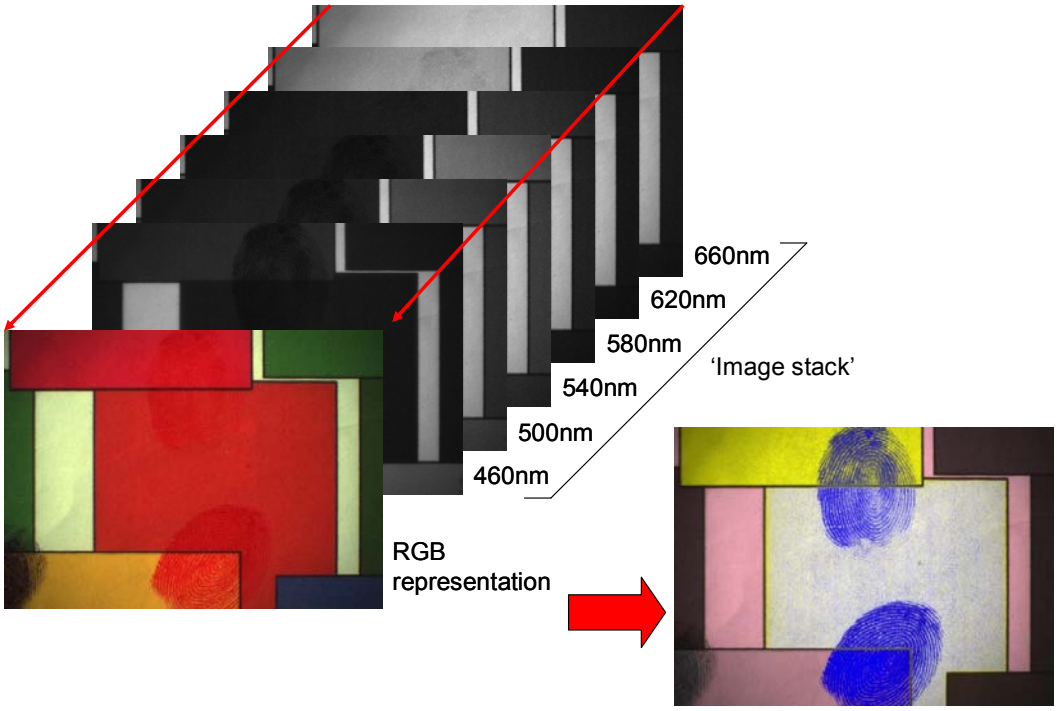


Prototype monochromator under test.

2. Theory

2.1 Multispectral imaging describes a range of techniques that all ultimately result in the capture of a digital image with spectral information associated with each pixel of that image. Such information may be obtained using either a single sensor capturing spectral information, which is then scanned across the area of interest [3], or an array of such sensors capable of capturing spatial and spectral information simultaneously [12-15]. These approaches are most often used for multispectral imaging in the IR region of the spectrum.

2.2 An alternative approach, more commonly used for multispectral imaging in the visible – near-IR – region, is to use a monochrome sensor array in combination with a tunable filter. Different tunable filter technologies are available, including liquid crystal and acousto-optical, but both types operate in essentially the same way. The tunable filter is a narrow bandwidth bandpass filter (typically with bandwidth in the range 2–20nm) for which the centre point of the bandpass can be controlled within the selected wavelength range. When carrying out multispectral imaging, the exhibit is illuminated with an appropriate light source and the tunable filter programmed to capture monochrome images at set wavelength intervals over the selected wavelength range. The series of monochrome images thus collected are known as an 'image cube' (or 'image stack') and can be interpreted by software to give a red-green-blue (RGB) , i.e. colour representation of the exhibit. An example is illustrated below.

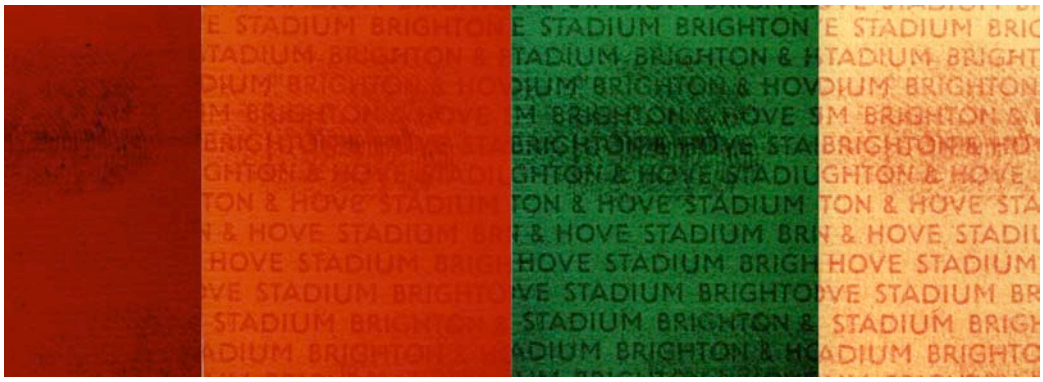


An example of an 'image cube' collected by a multispectral imager, the corresponding red-green-blue representation and unmixed image.

2.3 Once the image cube has been obtained, a range of processing techniques can be applied to the spatial and spectral information to extract the desired information. In the simplest form of analysis, regions with the desired spectrum (e.g. ninhydrin) can be identified, as can regions of unwanted background colour/pattern. These can be assigned false colours and the image unmixed to show the fingerprint in greater contrast. Alternatively, the regions corresponding to each colour channel can be viewed individually to see if any of these show the fingerprint more clearly than the unmixed image.

2.4 For images with multiple colours in the background and the fingerprint crossing several colour boundaries, other approaches such as Principal Component Analysis can be adopted to separate out the major spectral responses from the image, or a pure spectrum can be calculated from a subtraction from regions of background and mixed background/fingerprint spectrum.

2.5 Monochromatic illumination is an older and less versatile technique for revealing fingerprints on coloured backgrounds. In this technique a high intensity white light source is used in combination with a narrow bandwidth (~25nm) variable interference filter (typically a glass filter coated with a progressively thinner metal layer, giving a different transmitted colour along its length, e.g. the Schott glass Veril filter). The colour of the incident light can be controlled by moving the filter in front of a slit in the path of a light guide leading from the white light source, the objective being to match the incident colour with that of the printed background, thus suppressing it. If there is sufficient colour difference between the fingerprint and the background, this technique can be particularly effective.



a) b) c) d)

Mark in ninhydrin developed on patterned background viewed a) with red monochromatic illumination b) with orange monochromatic illumination c) with green monochromatic illumination and d) white light illumination.

2.6 Disadvantages compared with multispectral imaging are that the monochromator can only suppress one colour at a time and on multicoloured surfaces not all of the background will be removed. In addition, the bandwidth of the monochromator is generally broader than that achievable with tunable filters, and spectral differentiation will be correspondingly less.

3. CAST processes

3.1 CAST is in the process of evaluating the use of multispectral imaging for the capture of developed fingerprints and consequently a definitive method has not been devised. In the studies to date (2011), the

Cambridge Research and Instrumentation (CRi) 'Nuance' system has been utilised, consisting of a 1 megapixel digital camera integrated with a CRi 'Varispec' liquid crystal tunable filter with 7nm bandwidth and wavelength range 420–720nm. The 'Nuance' system has been fitted with a C-F mount adaptor and Nikon 105mm macro lens, bringing the camera sufficiently close to the exhibit such that the capture resolution is in excess of 500ppi. The exhibit is illuminated with a tungsten light source, and brought into sharp focus using the lens, viewing the image of the article on screen in the 'live' mode. The wavelength range of interest is selected, and the tunable filter set to collect a spectrum at 10nm intervals throughout the selected range. The filter is then set to calculate automatically the optimum exposure for each wavelength, and finally set to acquire the image cube. The operator can then carry out a variety of analysis tasks on the data contained in the image cube, such as Principal Component Analysis or calculation of pure spectra in order to separate the fingerprint from the background. For evidential purposes, it is recommended that the RGB representation of the exhibit, the unmixed image, the image associated with each spectral channel and the spectral information are retained. The wavelength range and step interval between spectra can be refined to the particular region of interest once the initial image cube has been obtained.

3.2 For monochromatic illumination using the Quaserchrome, the accessory should be fitted to the end of the light guide running from the Quaser light source. The light source should be set to the white light illumination mode, using the appropriate key to override the interlock. The dial on the Quaserchrome can then be rotated to move the filter in front of the slit in the path of the light guide, and the change in colour output can be observed by eye. Because the output is only a small region of the visible spectrum, the power is much reduced from normal Quaser excitation filters and consequently it is not necessary to wear viewing goggles. The mark to be imaged is viewed by eye as the illumination colour is varied, and the colour giving optimum contrast between the fingerprint and the background is selected for any subsequent photography.

3.3 The procedure using the integrated monochromator on IRIS is very similar. The light source selector switches should be set to the Quaser 2000, which should have 'white light' selected as the excitation band. The monochromator dial should then be turned until the orange light on the front of the Quaser 2000 is illuminated. Pressing the orange light illuminates the Quaser in the violet region of the spectrum and the illumination colour can be varied by continuing to turn the monochromator dial. The optimum illumination colour is either determined by eye or by viewing the semi-live image on the computer monitor.

4. Critical issues

4.1 For multispectral imaging, it is essential to ensure that the sample is as evenly lit as possible and that the light source used to illuminate it has a continuous output across the spectral range of interest. Best results for spectral discrimination are obtained from systems with narrow bandwidth filters and by collecting images at many closely spaced wavelengths.

5. Application

5.1 Suitable surfaces: The principal application for multispectral imaging and monochromatic illumination is in revealing developed fingerprints on articles with patterned and/or multicoloured backgrounds, as may be encountered on exhibits such as banknotes. Best results are obtained when the development process itself produces marks of a characteristic colour.

Mark developed using ninhydrin on patterned, multicoloured background of a £20 note.

5.2 Both techniques can be used to exploit differences between the colour spectrum of the developed fingerprint and the background printing. Monochromatic illumination is effective if only one background colour is prevalent, whereas multispectral imaging can be applied where many colours are present.

5.3 Both techniques are applied after chemical treatment to produce a coloured or fluorescent product, and are non-destructive, only involving illumination of the exhibit with a relatively low power light source.

6. Alternative formulations and processes

6.1 It is also possible to remove regular patterned backgrounds by means of fast Fourier transforms, a digital filtering technique. A Fourier transform is taken of the digital image and the features associated with the patterned background are identified. These are then masked and the inverse transform is taken, which suppresses the background pattern in the image and may reveal additional detail in the more irregular fingerprint [16,17]. However, fast Fourier transforms are most effective where the pattern is regular, and this is often not the case for many regions of banknotes. In these situations multispectral imaging or monochromatic illumination may yield better results.

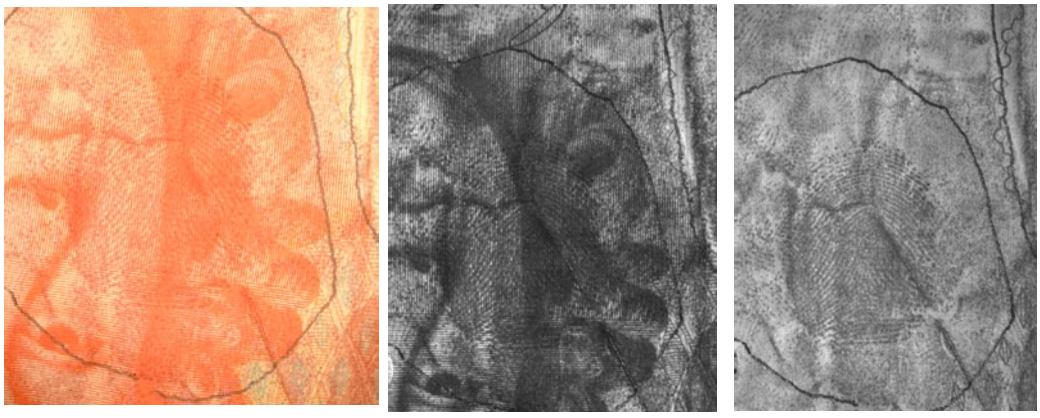
7. Post-treatments

7.1 There are no post-treatments used with monochromatic illumination. The principal post-treatment used with multispectral imaging is the analysis software used to extract the spectrum of the fingerprint reagent from those of the background.

8.Validation and operational experience

8.1 Multispectral imaging and monochromatic illumination are non-destructive techniques and can be used during a sequential process without detriment to subsequent treatments. As a consequence there is less of a requirement to conduct comparative laboratory experiments with other techniques or operational trials before implementing them on operational work.

8.2 Monochromatic illumination has been in use for 20 years on operational work. It is known to work well with ninhydrin marks on the Bank of England £50 note, the former ‘Edward Elgar’ £20 note and on some regions of the £10 note.



a) b) c)

Fingerprint developed using ninhydrin on a £50 note a) colour image illuminated with white light b) monochrome image illuminated with green monochromatic light and c) monochrome image illuminated with red monochromatic light.

8.3 Since 2007 multispectral imaging has been used on selected operational cases where marks have been developed but cannot be resolved by monochromatic illumination, IR imaging or digital filtering techniques such as fast Fourier transforms. In several of these cases entire marks or additional ridge detail have been revealed, leading to successful identifications and convictions.

a) b)

Fingerprint in coloured contaminant found on a £10 note a) red-green-blue image and b) unmixed image showing fingerprint extracted from the background by spectral characteristics (courtesy of Nick Marsh, Metropolitan Police Service).

9. References

1. **Exline, D. L., Wallace, C., Roux, C., Lennard, C., Nelson, M. P. and Treado, P. J.** (2003) 'Forensic applications of chemical imaging: latent fingerprint detection using visible absorption and luminescence', *J. Forens. Sci.* vol. 48, pp 1047–1053.

2. **Payne, G., Reedy, B., Lennard, C., Comber, B., Exline, D. and Roux, C.** (2005) 'A further study to investigate the detection and enhancement of latent fingerprints using visible absorption and luminescence chemical imaging', *Forens. Sci. Int.,* vol. 150 (1), pp 33–51.

3. **Tahtouh, M., Kalman, J. R., Roux, C., Lennard, C. and Reedy, B. J.** (2005) 'The detection and enhancement of latent fingermarks using infrared chemical imaging', *J. Forens. Sci.* 50, pp 1–9.

4. **Crane, N. J., Bartick, E. G., Perlman, R. S. and Huffman, S.** (2007) 'Infrared spectroscopic imaging for non-invasive detection of latent fingerprints', *J. Forens. Sci.*, vol. 52 (1), pp 48–53.

5. **Tahtouh, M., Despland, P., Shimmon, R., Kalman, J. R. and Reedy, B. J.** (2007) 'The application of infrared chemical imaging to the detection and enhancement of latent fingerprints: Method optimisation and further findings', *J. Forens. Sci.,* vol. 52 (5), pp 1089–1096.

6. **Flynn, K., O'Leary, R., Lennard, C., Roux, C. and Reedy, B. J.** (2005) 'Forensic applications of infrared chemical imaging: Multilayered paint chips', *J. Forens. Sci.,* vol. 50 (4), pp 832–841.

7. **Flynn, K., O'Leary, R., Roux, C. and Reedy, B. J.** (2006) 'Forensic analysis of bicomponent fibres using chemical imaging', *J. Forens. Sci.,* vol. 51 (3), pp 586–596.

8. **Payne, G., Wallace, C., Reedy, B., Lennard, C., Schuler, R., Exline, D. and Roux, C.** (2005) 'Visible and near-infrared chemical imaging methods for the analysis of selected forensic samples', *Talanta*, vol. 67 (2), pp 334–344.

9. **Bandey, H., Bleay, S., Bowman, V., Fitzgerald, L., Gibson, A., Hart, A. and Sears, V.** (2006) 'Fingerprint imaging across EM spectrum', *Imaging Sci. J.,* vol. 54, pp 211–219.

10. **Bacon, C. F.** (1989) *Optimisation of the Photographic Recording of Fingerprints on Paper; Methods of Predicting these Results*, Project Report for BSc Photographic Sciences*,* May 1989. Faculty of Communication, Polytechnic of Central London.

11. **PSDB** (2003) *The IRIS Latent Fingerprint Workstation*, PSDB Information Leaflet, November. London: Home Office.

12. **Chan, K. L. A. and Kazarian, S. G**. (2006) 'Detection of trace materials with Fourier Transform infrared spectroscopy using a multi-channel detector', *Anal.*, 131, pp 126–131.

13. **Ricci, C., Chan, K. L. A. and Kazarian, S. G.** (2006) 'Combining the tape-lift method and Fourier transform infrared spectroscopic imaging for forensic applications', *Appl. Spectrosc.,* vol.60 (9), pp 1013–1021.

14. **Ricci ,C., Phiriyavityopas, P., Curum, N., Chan, K. L. A., Jickells, S. and Kazarian, S. G.** (2007) 'Chemical imaging of fingerprint residues', *Appl. Spectrosc.,* vol. 61 (5), pp 514–522.

15. **Ricci, C., Bleay, S. M. and Kazarian, S. G.** (2007) 'Spectroscopic imaging of latent fingermarks collected with the aid of a gelatine lifter', *Anal. Chem*., 79 (15), pp 5771–5776.

16. **Dalrymple, B. and Menzies, T.** (1994) 'Computer enhancement of evidence through background noise suppression', *J. Forens. Sci.,* vol. 39 (2), pp 537–546.

17. **Blitzer, H. L. and Jacobia, J.** (2002) *Forensic Digital Imaging and Photography*, . ISBN 0-12-106411-5. London: Academic Press.