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ScienceDirect

Forensic Science International 178 (2008) 46–53

Forensic Science International

www.elsevier.com/locate/forsciint

The quantification of fingerprint quality using a relative contrast index

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Received 12 October 2007; received in revised form 31 January 2008; accepted 7 February 2008

Available online 24 March 2008

Abstract

Research into fingermark enhancement techniques has traditionally used visual comparisons and qualitative methods to assess their effectiveness based on the quality of the developed fingermark. However, with increasing research into the optimisation of these techniques the need for a quantitative evaluative method has arisen. Parameters for acceptable fingerprint quality are not well defined and generally encompass clear, sharp edges and high levels of contrast between the fingermark ridges and background material. Using these current parameters, a conclusive measurement of fingerprint quality and thus the effectiveness of development techniques cannot be achieved.

This study presents a model through which an aspect of fingerprint quality can be objectively and impartially measured based on a relative contrast index, constructed through measuring the reflective intensity of the fingermark ridges against the background material. Using a fibre-optic spectrophotometer attached to a microscope with axial illumination, the intensity counts of the ridge detail and background material were measured and a logarithmic contrast index constructed. The microscope and spectrophotometer parameters were experimentally tested using a standard colour resolution chart with known reflective properties. The protocol was successfully applied to four sample groups: black inked fingerprints on white paper; latent fingermarks on white paper developed separately with ninhydrin and physical developer; and fingermarks in blood deposited on white tiles and enhanced with amido black. The contrast indices obtained quantitatively reflect the level of contrast and provide an indication of fingerprint quality through a numerical representation rather than previous qualitative methods. It has been suggested that the proposed method of fingerprint quantification may be viable for application in the forensic research arena as it allows the definitive measurement of contrast to aid the evaluation of fingermark detection and enhancement techniques.

Keywords: Contrast index; Fingerprint development; Amido black; Ninhydrin; Physical developer; Fingermarks; Fingerprints

1. Introduction

Fingerprint identification is an important tool used in law enforcement as a method of identifying suspects and victims of crime and providing physical evidence for prosecution. Techniques for latent fingerprint development are constantly being researched to enable better enhancement methods. The purpose of treating latent fingermarks is to enable visualisation of the fingermark through producing contrast between the ridges and the background material, while retaining the level detail present in the latent mark. Visualisation of the fingerprint is a key principle to enable a forensic analysis in the form of a visual comparison. Contrast, defined as the difference between extremes [1], is thus a principal parameter of fingerprint quality.

The quantification of other factors are currently being developed and implemented, including quantifying the luminescence of DFO-treated fingermarks [2]; measuring the amount of gold deposited in vacuum metal deposition [3] and quantifying the amount of cyanoacrylate deposited after fuming [4]. However, these factors do not necessarily contribute to fingerprint quality. Without an adequate level of contrast between the ridges of the fingerprint and the background material, the ability to perform an analysis is significantly reduced as a complete lack of contrast renders the fingerprint invisible. The higher the tonal difference between the ridges and the valleys, the more distinguishable the print.

Simultaneous contrast is a phenomenon that may alter the perceived quality of fingerprints and thus affect the subjective visual examinations currently implemented. Simultaneous contrast is a deficiency in human vision that refers to the perceived interaction of two adjacent colours or tones [5]. In inked fingerprints this illusion can cause the valley areas

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doi:10.1016/j.forsciint.2008.02.003

between the fingerprint ridges to appear light grey and not white.

Another aspect of fingerprint quality is clarity or sharpness of ridge detail. For example, a detection technique that produces good contrast may still be unacceptable if it results in ridge diffusion and therefore loss of ridge clarity. This aspect of fingerprint quality is not considered in this study.

1.1. Quality assessment methods

While fingermark enhancement techniques improve and become more sensitive, the method of quality assessment has not evolved to the same extent. The most common method of quality evaluation used to compare different fingerprint enhancement reagents and assess their effectiveness is through visual comparison [6–11]. This method is highly subjective and problematic as vague statements such as 'excellent print qualities' [12], 'clear ridge detail' [13] and 'excellent definition' [14] are often presented. Visual evaluation methods have unclear and undefined quality parameters without any accepted standards. A standard regarding the measurement of contrast may provide clear definitions of quality for future fingermark development researchers and would eliminate the vague parameters currently used.

However, while many authors merely allude to fingerprint quality, a select few identify the parameters and methods used in assessing the quality of the prints developed in their research. A quality ranking scale presented by Almog et al. [15] was based on the development rate of the fingerprints, calculated by counting the fingerprints with 8 or more minutiae evident over a two-week period. Bialek et al. [16] similarly determined whether the clarity of the print had been improved with enhancement by creating a scale based on the number of minutiae visible in blood fingermarks before and after treatment occurred. These systems rely on the competent identification of minutiae however and their use by untrained scientific researchers may lead to inaccurate results that cannot be confidently compared across other research projects.

Aberrations in fingerprint images used in automated fingerprint identification systems (AFIS) can cause false rejections or acceptances, resulting in significant problems when using the system for identification purposes [17]. The algorithms used in these systems to filter and verify the images perform an image quality analysis [17–20] designed for application to digital images captured using fingerprint sensors. While the algorithms present various methods to assess fingerprint quality, they cannot be applied to physical items of evidence without first photographing the fingerprint. The photographic process may affect the fingerprint quality through the addition of 'noise' to the image. However, studies into the algorithms used in fingerprint image quality analysis emphasise the potential issues associated with matching fingerprints using poor quality prints [17]. It is thus imperative that detection and enhancement methods produce high quality fingermarks that can maximise their use for identification purposes.

A study of the current forensic science literature failed to find any quantification models relating to fingerprint development research. The aim of this study is to fill a gap in the scientific knowledge by developing a novel quantitative method to numerically represent fingerprint contrast as one aspect of fingerprint quality. It is understood the model is a new concept for fingerprint research.

1.2. The contrast index

The widespread use of relative indices in forensic areas including photography [1], motor accident investigation [21], anthropometric studies [22,23] and bite mark analysis [24] prompted their application in this research. The key concept that the contrast index needed to provide was a meaningful scale in which the values related to each other and were not arbitrary. For this reason a simple ratio was excluded and a logarithmic scale was explored, as a 0.3 increase in a logarithmic scale represents a two-fold increase in the item being measured. The contrast index constructed was:

$$\text{contrast index} = \log_{10}\left(\frac{V}{R}\right)$$

where V is the reflective intensity of the fingerprint valleys and R is the reflective intensity of the ridges.

Additionally, the logarithmic contrast index does not have any theoretical upper limit that must be defined which is more realistic due to the unknown extent to which contrast may be measured; however, practical limits may be observed through experimental work. The lower limit of the contrast index scale is 0 which is obtained if the ridge and valley intensities are equal, thus indicating no contrast.

2. Materials and methods

The spectrophotometer used in this study was the Ocean Optics HR2000 High Resolution Fibre Optic Spectrophotometer. It was attached via a fibre optic to the top of a Leica microscope to allow the data collection from the experimental fingermarks. The microscope was necessary to isolate the fingerprint ridges and valleys for accurate measurement and a magnification of 200× was used. All filters in the microscope were disengaged for this work. Standardised spectrophotometer settings were used during data collection to ensure consistency. The integration time was set at 10 ms; boxcar and averaging functions were each set to 5 and the lamp set to 12 (maximum) and allowed to warm up for 1 h prior to data collection occurring. All spectrum were visualised with OOIBase32 software, program Version 2.0.6.5.

Ink and latent fingermarks were used as test samples in this study. Fingermarks of ideal clarity and resolution were used in this research because the proposed model is intended for application in fingerprint research laboratories where ideal fingermarks could also be employed. However, it is recognised that weak or depleted fingermarks are also used in research and the contrast index model can be applied to other forms of fingermark results including fluorescence methods. A rubber stamp was made from an inked fingerprint impression to improve consistency of the clarity of the deposited fingermarks and provide repeatability in the experimental design.

2.1. Fingerprint deposition

The fingerprint stamp was used to deposit prints in black EasyPrint® EP-15 fingerprint ink, which were deposited on white Fuji Xerox Performer +® copy paper in a depletion series (Fig. 1). The first print was deposited after freshly inking the stamp and 4 subsequent prints were deposited before the stamp was

Fig. 1. Inked fingerprint depletion series.

re-inked. Only the first three prints in the depletion series were extensively analysed in this study, denoted print 1 for the initial ink print, 2 for the second and 3 for the third print in the series.

Latent fingermarks were deposited onto white paper with a second rubber stamp. The stamp was loaded with sebaceous residues by rubbing the forehead of a 21-year-old female donor prior to placing the stamp on the paper for 10 s. Latent fingermarks were also deposited naturally by a 22-year-old male donor, who loaded his right thumb with sebaceous residues by rubbing his forehead and nose before placing his thumb lightly on the paper for 10 s. The prints were deposited after physical activity in an attempt to maximise the amount of eccrine and sebaceous residues deposited.

Fingermarks in defibrinated horse blood (Serum Australis HD290607DF) were also deposited onto white matte tiles with the rubber stamp. A paper towel was soaked in the blood to form a type of ''ink pad'' onto which the rubber stamp was gently pressed to obtain even coverage.

2.2. Ninhydrin treatment

Ninhydrin was used to develop 120 latent fingermarks, which were 1 day old. The ninhydrin formulation contained 0.4% (w/v) ninhydrin, 0.8% (v/v) acetic acid, 1.6% (v/v) ethanol and 5% (v/v) isopropyl alcohol in 92% (v/v) Forane® 141B (1,1-dichloro-1-fluoroethane). The sheets of paper on which the latent prints were deposited were immersed in the ninhydrin solution until they were completely saturated. They were then removed and hung up to dry. Once the sheets were dry they were stored in an envelope until analysis was carried out. The prints took several days to develop which is typical of this process, however to ensure maximum development before analysis, the paper was subjected to a steam and heat press for 5 s to accelerate the ninhydrin reaction.

Only 40 of the fingermarks developed with ninhydrin were selected for the experimental analysis, based on the strength of the Ruhemann's purple colour that had developed. Some of the prints that had developed were very faint, and were excluded from the study in an effort to maintain a consistent level of colour intensity across the sample group.

2.3. Amido black treatment

Amido black was used to enhance 40 fingermarks in blood aged for 7 days. Before treatment, the blood marks were fixed to prevent smearing of the blood by submerging the tiles in 100% methanol for 15 min. The tiles were then immersed in the stain solution for 3 min, before being rinsed with a sequence of washing solutions to de-stain the background [16]. The staining solution comprised 0.2% (w/v) acid black 1, 10% (v/v) acetic acid and 89.8% methanol [25]. The first rinse was done with washing solution A which contained 10% acetic acid in methanol, before being transferred to washing solution B containing 5% acetic acid in distilled water. The tiles were finally rinsed in distilled water and were then left to air-dry before analysis was carried out.

2.4. Physical developer treatment

Physical developer was used to develop 60 latent fingermarks which were 3 days old. Maleic acid is commonly used as an acid pre-wash; however, 1% nitric acid was suggested for use in this study after initial trials using maleic acid returned very poor results. The physical developer working solution contained 5% silver nitrate solution (20%, w/v) and 95% redox solution [25]. The redox solution comprised 3% (w/v) ferric nitrate, 8% (w/v) ferrous ammonium sulfate, 2% (w/v) citric acid and 4% (v/v) detergent–surfactant stock solution in water [25]. The paper was washed in distilled water prior to placement in the acid prewash for 3 min. The paper was then rinsed briefly and submerged in the physical developer solution until the fingermarks began to develop. The paper was removed after about 5 min, when the background of the paper was beginning to discolour. The prints were left to air dry before analysis was undertaken.

2.5. Reference standard

A GretagMacbeth ColourChecker® reference standard was used as a control in this research (Fig. 2). The reference standard consists of 24 colours that have known colour and reflective properties described by Munsell notation. The Munsell notation standard descriptive colour system assigns absolute black a value of 1 and absolute white a value of 10 [26]. The black and white squares in the reference standard have values of 2 and 9.5, respectively [27]. The four shades of grey and the black and white squares were measured using the spectrophotometer and microscope under the same conditions as the fingermarks. Forty measurements were randomly taken within each square, which were then averaged using Microsoft Excel software. The data collected were used to test the viability of the proposed contrast index. It also provided an experimental range of contrast indices produced using known grey values.

2.6. Data collection and analysis

Each fingerprint was measured using the spectrophotometer and all spectra obtained were imported into Microsoft Excel for data analysis. The first 10 ridges and valleys radiating from the core of each fingerprint were measured for consistency purposes, however the direction in which this line radiated was chosen randomly for each print.

The mean spectrum from the 400 ridge and valley measurements (10 readings from 40 fingermarks) were calculated to obtain a representative spectrum for each sample group. The spectrum were also averaged to eliminate slight errors that may have occurred in the measurement process, such as small fluctuations in the light source output during the period of time that the fingermarks were measured. The data collected from the colour chart were also averaged to obtain the mean spectrum for each standard grey tone.

Data analysis tests were carried out to determine the best way in which to analyse the spectrum in order to obtain one value that accurately represented the spectral data and could be inserted into the contrast index formula. The first test substituted the maximum value from each spectrum into the formula and the

Fig. 2. GretagMacbeth ColourChecker® reference standard.

second analysis method obtained the mean from bandwidths centred on the maximum value. The mean of bandwidths 10, 25 and 50 nm either side of the maximum value were calculated from the mean spectrum collected for the reference standard and fingerprint test groups.

The third method of analysis involved finding the area under the curves through integration. This involved the summation of all intensity count readings above 3 to produce a single number to substitute into the contrast index formula. The maximum value of the noise spectrum was 2.977 intensity counts, and thus the value of 3 was determined as the threshold that would eliminate the majority of the electrical noise to obtain the most accurate result.

3. Results

3.1. Data analysis tests

The results of the data analysis tests are summarised in Table 1. Surprisingly, all the contrast values display relative consistency regardless of the data analysis method used in the calculation and the standard deviation values illustrate only a slight variance. The maximum values for the ridges of the coloured amido black and ninhydrin prints do not occur in the same region as the valley maximum due to the shape of the curves, which may have caused slight variations to occur between the mean bandwidth and integration data analysis methods.

While the values calculated using the different methods do not differ significantly, the integration method incorporates data from the entire spectrum and thus was chosen as the data analysis method for the contrast index. It appears that the integration method more accurately allows for spectrum that display two peaks or that differ in shape from the normal curve (Fig. 3).

The contrast indices for each of the fingerprint sample groups were thus calculated by integrating the mean spectrum. The integration value for the valley curve was substituted into the contrast index formula as V, and the integrated value of the ridge curve was substituted as R.

3.2. Reference standard

The reference chart provided absolute black and white, and grey tones with known colour and reflective properties which were used as controls in this experimental work (Fig. 4a). The measurement of the reference chart allowed the calculation of contrast indices from standard samples to evaluate the effectiveness of the contrast index formula.

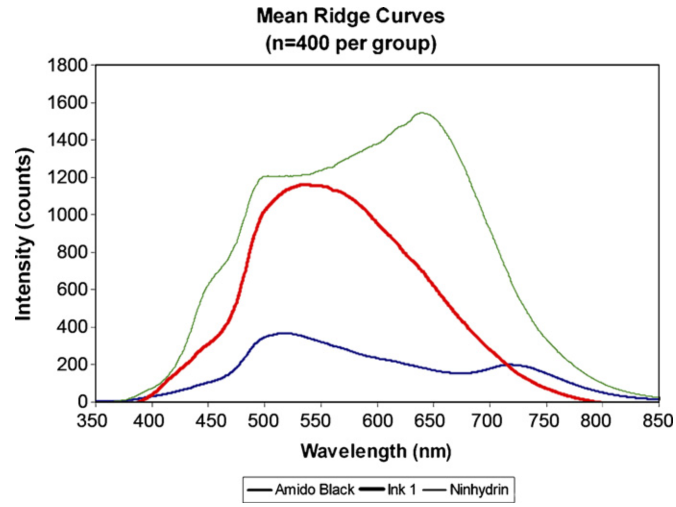

Fig. 3. Example of the differing ridge curve shapes.

The contrast index values calculated from the standard reference illustrate a relationship between the reflective intensity of the grey value and the contrast between that grey tone and white (Table 2). This provides evidence that the contrast index produces meaningful results and suggests that the index may be viable for application as a quantitative contrast determination method in fingermark detection and enhancement research.

3.3. Inked fingerprints

The inked fingerprints were used as an internal standard in this project as they provided a series of fingerprints that ensured relatively consistent levels of contrast within each ink sample group. As was expected, the contrast indices successively decreased as the prints of the depletion series became fainter, with Ink 1 showing higher levels of contrast than the Ink 2 and Ink 3 fingerprints (Fig. 4). The step-wise decrease in contrast indices between the three inked fingerprint groups illustrates a consistent decrease in the amount of ink deposited by the fingerprint stamp in the depletion series. The contrast values

Table 1
Contrast indices calculated in data analysis testing

	Maximum value	50 nm bandwidth	25 nm bandwidth	10 nm bandwidth	Integration value	Standard deviation
Black[a]	1.390	1.390	1.391	1.392	1.388	0.002
Dark grey[a]	0.984	0.983	0.983	0.983	0.991	0.003
Medium grey[a]	0.714	0.715	0.713	0.714	0.729	0.007
Light medium grey[a]	0.400	0.402	0.400	0.400	0.410	0.004
Light grey[a]	0.193	0.194	0.193	0.193	0.201	0.003
Ink 1	0.493	0.491	0.492	0.493	0.511	0.008
Ink 2	0.243	0.244	0.243	0.243	0.251	0.003
Ink 3	0.128	0.129	0.128	0.128	0.132	0.002
Amido black	0.690	0.727	0.700	0.693	0.636	0.033
Ninhydrin	0.321	0.340	0.330	0.323	0.267	0.029
Physical developer	0.160	0.160	0.160	0.160	0.158	0.001

[a] The reference standard contrast indices were calculated substituting white as the "valley" and the grey tone as the "ridge" in the contrast index formula

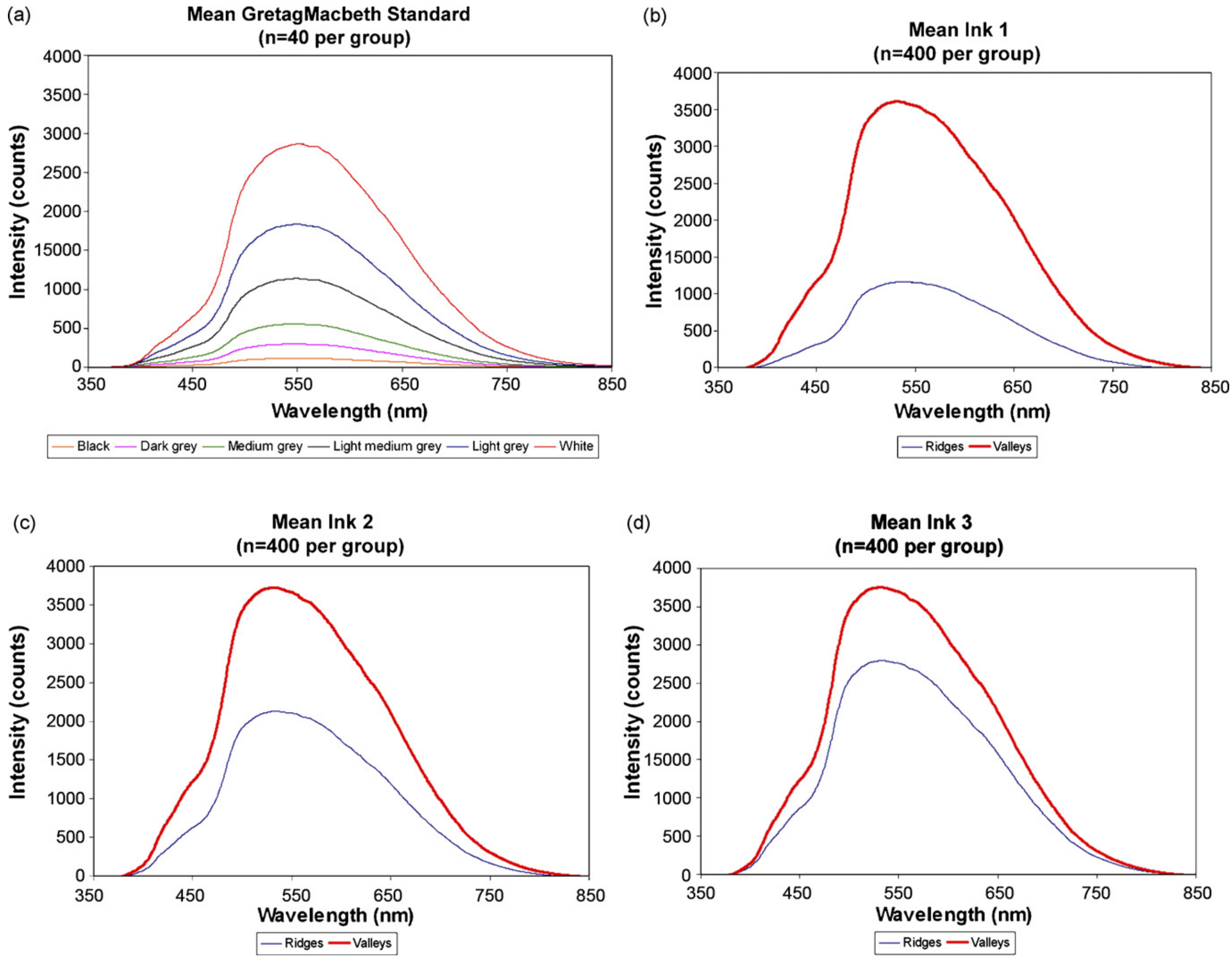

Fig. 4. Mean spectrum from (a) reference standard; (b) Ink 1; (c) Ink 2; (d) Ink 3.

also suggest a successive reduction in the quality of the ink prints in groups 2 and 3, respectively.

3.4. Chemically enhanced fingermarks

The ninhydrin curve (Fig. 5a) has a broader bandwidth regarding the maximum intensity and does not produce a single, defined peak. The shape of this curve, due to the Ruhemann's purple colour developed, is the reason why the 'integration of the curves' analysis method was applied.

Similarly, the amido black mean spectrum (Fig. 5b) shows a broad curve produced by the blue-black colour of amido black when used to enhance fingermarks in blood. It is interesting to note with this spectrum that, despite the lower intensities recorded for the fingermark ridges, amido black produced the highest contrast index values. These results provide evidence to suggest the amido black enhancement technique produces higher contrast levels than the inked prints and other enhancement methods applied in this research. The mean physical developer spectrum (Fig. 5c) illustrates the smallest difference in reflective intensity between the ridges and valleys of the treated fingermarks. This small difference between the ridge and valley curves produced the lowest contrast value of the chemically enhanced fingermarks.

Table 2
Mean contrast indices

Standard grey tone	Contrast index	Sample group	Contrast index
Black	1.388	Amido black	0.636
Dark grey	0.991	Ink 1	0.511
Medium grey	0.729	Ninhydrin	0.267
Light medium grey	0.410	Ink 2	0.251
Light grey	0.201	Physical developer	0.158
White	0	Ink 3	0.132

3.5. Variance

The contrast index for each individual fingerprint within the sample groups was also calculated, and Fig. 6 illustrates the distribution of the individual contrast indices. The standard deviation of the contrast index within each sample group indicates the variance between the individual fingermarks (Table 3). Larger variances are evident in the

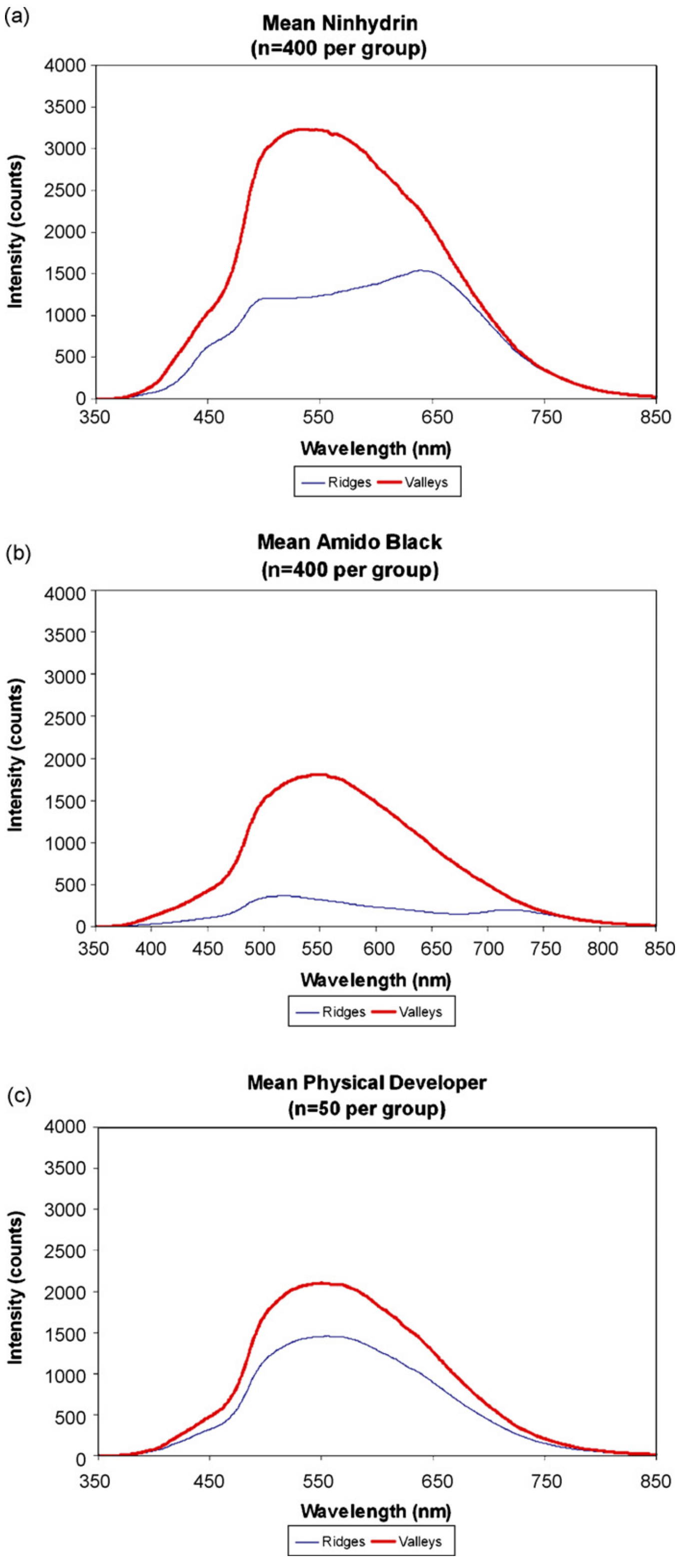

Fig. 5. Mean spectrum from chemically enhanced fingermarks (a) ninhydrin; (b) amido black; (c) physical developer.

ninhydrin and physical developer sample groups than in the Ink 1 and 2 sample groups however this may be attributed to variables encountered in the fingerprint deposition process.

The depletion series with the inked fingerprints ensured relative consistency with the contrast levels in each of the ink

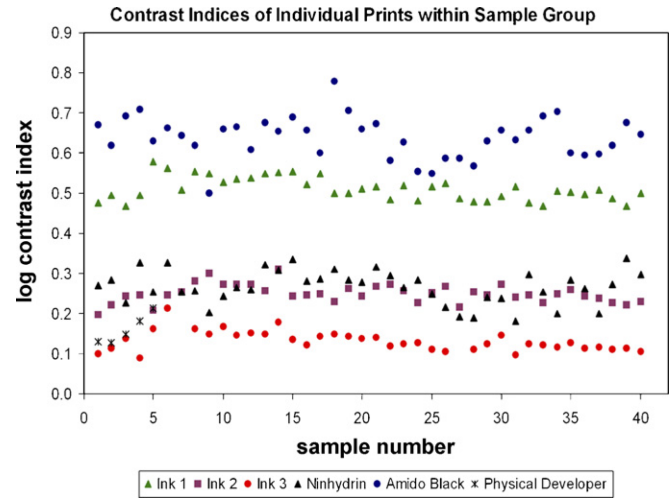

Fig. 6. Contrast indices of individual prints in each sample group (the physical developer method has only 5 samples due to difficulties encountered with processing).

sample groups as the fingerprint stamp deposited a similar amount of ink for each print in the depletion series. However, the blood and latent fingerprint deposition process was unable to be as closely controlled and variable factors may have contributed to the differences evident between each of the individual fingermarks. The errors evident in the Ink 3 and physical developer sample groups may be due to difficulties encountered in the measurement process as the fingermarks in these groups were very faint.

4. Discussion

The contrast index presented in this research provides numerical representation of fingerprint quality through measuring the contrast between the ridges and valleys of the print. The results demonstrate the viability of the model and the clear relationship between the contrast indices and the quality and level of contrast within each fingerprint. The range of values obtained through the measurement of the reference standard provides evidence for the feasibility of the contrast index model and the logical and meaningful results that can be obtained.

The spectrum obtained from the fingerprint samples indicates the differing levels of contrast in each of the fingermarks, and this difference is subsequently shown in the contrast indices. As was expected, the amido black fingermarks

Table 3
Variances of individual contrast indices within sample group

Sample group	Mean contrast indices	Standard deviation	Standard error
Ink 1	0.511	0.029	0.0046
Ink 2	0.251	0.023	0.0037
Ink 3	0.132	0.025	0.0040
Amido black	0.636	0.052	0.0083
Ninhydrin	0.267	0.042	0.0067
Physical developer	0.158	0.037	0.0167

Amido Black 0.636 *Ink 1 0.511* *Ninhydrin 0.267* *Ink 2 0.251* *Physical Developer 0.158* *Ink 3 0.132*

Fig. 7. The fingermarks enhanced in this study and their relative contrast index values.

produced a higher level of contrast than the ninhydrin prints and the physical developer fingermarks displayed the lowest contrast in these experiments (Fig. 7).

The contrast indices for the individual fingermarks illustrate the variability in each of the sample groups. The inked fingerprints produced fairly consistent results as a similar amount of ink coated the stamp with each reloading and was transferred to the paper with each deposition.

The contrast indices for the amido black, ninhydrin and physical developer fingermarks were slightly more variable which is most likely due to variables encountered in the deposition process. The amount of amino acid and sebaceous residues deposited for the ninhydrin and physical developer treatments was random although efforts were made to use only two fingerprint donors and to ensure fingers were loaded with sebaceous residues before each deposition. The amount of blood coating the fingerprint stamp was also difficult to consistently maintain during the deposition of the blood prints. Difficulties in measuring the fingermarks under the microscope were also encountered due to the variability in the appearance of the fingerprint ridge size, density and shape.

It is clear that the results obtained in this study support the concept of a relative contrast index. The contrast indices quantitatively reflect the level of contrast in fingermarks through numerical representation, illustrating the viability and application of the model in future fingerprint research.

5. Conclusions

The contrast index model is a novel method to quantitatively measure fingerprint quality. Qualitative visual evaluations are currently used by many researchers however these methods are highly subjective. The quantitative model presented in this study provides a simple and effective method to numerically represent the level of contrast in enhanced fingermarks. Additional research is required to further demonstrate the potential of this model, and development for use on fluorescent enhancement techniques is recommended. Nevertheless, this novel technique has been successfully applied to fingermarks developed with ninhydrin, amido black and physical developer. The model may now be applied in fingerprint research laboratories to determine the effectiveness of fingerprint reagents based on the level of contrast produced and may become a standard method in future fingerprint research as a means of numerically represent fingerprint quality.

Acknowledgements

The authors would like to thank Detective Senior Constable Mark Lipman and the staff of the NSW Police Fingerprint Laboratory for their assistance with the chemical development of the fingerprints in this study.

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