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The investigation of a relative contrast index model for fingerprint quantification

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ABSTRACT

The quantification of fingerprint contrast is a relatively new concept in fingerprint enhancement research. It has emerged as a mode of fingerprint assessment to reduce the potential biased of visual qualitative assessment. Subjective qualitative methods that are currently reported in the literature include; side-by-side assessment, assigning a score to a treatment based on visible criteria and stating observed results without presenting supporting validation. These qualitative methods often do not state clearly the visual assessment parameters and produce a degree of ambiguity when defining the enhancement results.

The relative contrast index model was constructed to empirically quantify the difference in contrast between fingerprint ridges and valleys, using measurements gained from a microspectrophotometer. This paper seeks to further investigate this recent research and test the model using three different microspectrophotometers. Data from these separate sources will determine whether the theoretical aspects of the model would pragmatically produce reliable and repeatable results across a range of microspectrophotometers found in forensic laboratories.

1. Introduction

Latent fingermark enhancement is an active research arena. Enhancement techniques that are routinely used may not always be ideal for all surfaces, may be ineffective for weak latent traces and may not reveal enough detail for identification. Particular areas of ongoing fingermark research include; the optimisation of new fingermark detection techniques, new powder formulations using dyes and emerging nanotechnology, employing new optical techniques and digital image processing [1].

A survey of the fingerprinting literature revealed that several qualitative methods are currently used in research to describe fingermark development and enhancement results [1–46]. A review of the literature was conducted using specific criteria to determine the type, extent and frequency of fingermark assessment methods and categorised them according to the type of enhancement researched (reagent-based, metal deposition, powders, latent blood and other). The various methods of describing fingermark enhancement results are shown in Fig. 1.

The key criteria during the literature review were the number of fingermark enhancement images that were presented and classifying any visual assessment as 'defined',[1] 'not clear' [2] or 'undefined' [3] depending on how clearly the assessment parameters were stipulated in each paper. Qualitative visual assessments of results were made across all articles within the review. Furthermore, it was noted if any quantification of the resultant fingermark enhancement was attempted and if so, what type of quantification was used. The frequency of visual comparisons, visual scores, side-by-side comparisons and the numbers developed were also determined. The production cost and development time were also factors that were not specifically related to the enhancement but do numerically quantify an aspect of the method. Table 1 illustrates the results of the literature review.

The quantification of contrast has recently emerged as a numerical alternative to the subjective and often ambiguous

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[1] 'Defined' category was used when the article clearly explained the parameters used for enhancement evaluations. For example *"Stained prints were analysed for level I and level II detail. If the ridge flow or pattern of the fingerprint was identifiable, it was considered to posses level I detail. The presence of level II detail included the observation of bifurcations, ridge endings, a clear core area or one or more deltas"* [28].

[2] 'Not clear' category is defined when parts of the qualitative assessment are explained, however, not made completely clear.

[3] 'Undefined' category was used when results were described without any explanation regarding the assessment parameters. For example; *"Staining of fingerprints was patchy and less dark"* [30] and *"Excellent definition was seen in both cases"* [26].

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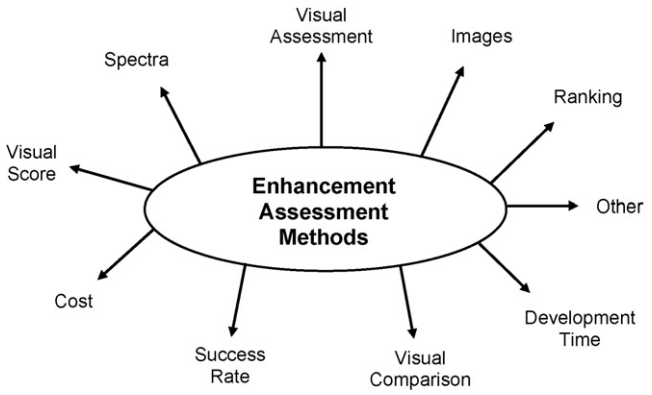

Fig. 1. Methods of describing fingermark enhancement results used in current literature.

qualitative assessment methods. The relative contrast index (RCI) measures the difference in contrast between fingerprint ridges and valleys using a microspectrophotometer [47]. It provides a numerical or logarithmic value of contrast that is comparable between treatments. It also eliminates visual effects from influencing the visual assessment of a specific technique.

$$\text{Relative contrast index} = \log_{10}\left(\frac{\text{Valley intensity}}{\text{Ridge intensity}}\right)$$

The relative contrast index method uses spectra from fingermark valleys and ridges using a microspectrophotometer and the numerical values required for the relative contrast index are obtained by integrating the area under the spectral curve and applying the model's formulae. In theory, due to the relative nature of the contrast index, the model should produce consistent results for the same specimen when using different instruments. The principal objective of this research was to examine the relative contrast index and determine whether these values are consistent using different microspectrophotometers found within forensic science laboratories.

1.1. Measurement mode

The initial microspectrophotometer used in the development of the relative contrast index model [47] had the capacity to measure spectra in 'reflective', 'transmission' and 'scope' modes. The initial RCI model was developed using 'scope mode' which is a measurement mode that uses 'intensity counts' as the measurement of reflected light detected. The dedicated instruments used in this research did not have the 'scope' mode capacity. 'Percentage reflection' mode was considered as a more viable measurement mode.

A preliminary experiment for this research required testing the original instrument in both 'scope' and 'percentage reflection' modes to determine whether the relative contrast index results would be equivalent. Spectra were measured in both 'scope' and 'percentage reflection' modes, keeping all other settings identical including the sample area. The difference between the scope and percentage reflection modes was considered negligible but for the purpose of this study, all microspectrophotometer instruments were utilised in 'percentage reflection' mode to ensure a standardised approach.

2. Materials and methods

Three different microspectrophotometers were selected to measure the experimental sample material and determine whether the relative contrast index would remain the same throughout each instrument. The following instruments and operational parameters were used:

2.1. Instrument 1 – Leica DMR and Ocean Optics HR2000

Instrument 1 was a non-dedicated instrument that linked an Ocean Optics HR2000 spectrophotometer by a coaxial probe to the camera mount of the Leica DMR microscope. The OOIBase32 software program version 2.0.6.5 was opened to process the spectra. The spectrophotometer had fixed specifications with the entrance aperture set at 50 μm, slit width of 25 μm, optical resolution of 0.1 nm, composite diffraction grating that ranged 200 nm to 1100 nm. The integration time was set to 10 ms. The boxcar and averaging functions were each set to 5. All other functions were either set to 0 (zero) or were not selected.

The microscope lamp brightness was set to the maximum and the lamp was allowed to warm up for a minimum of 60 min before use. Any light filters on the microscope were all disengaged. The total magnification was ×400 with the combination of the eyepiece (×10) and the objective lens (×40). A large magnification was used to compensate for the large sampling area read by the spectrophotometer.

2.2. Instrument 2 – Leica Aristomat and Leitz MVP SP

The Leica Aristomat microscope was fitted with a dedicated Leitz MVP SP spectrophotometer. This instrument was also formerly used by law enforcement for forensic casework. The Leica Spectra Program, version 1.32 for Windows 95, was opened to process the spectra. In the adjustment window, the sensitivity was set at 7.5%, microscope lamp brightness was set at 50% and the 'active' box had the eyepiece flaps box checked. The lamp shutter key was selected for all the measurements. The low pass box had the 3000 Hz low pass filter selected. All optical filters were disengaged by selecting 'open'. The 'equalize' box was left blank.

In the measurement window, the miscellaneous box had the spectral option ticked. The interval was set at the lowest value possible, 0.1 s. Display also had spectrum selected. Colorimetry values had light type A and colour model XYZ selected. The spectrum box had a range of 400 nm to 700 nm, with the limit set to 0 (zero) and delta 3 selected. Measurement mode had 'reflectance' selected with smooth set to 5 and number of scans set to 5 (by default 8). Additive was not selected. The photometer field diaphragm had the two levers parallel to the red dot. The microscope lamp was allowed to warm up for a minimum of 60 min before readings were taken.

2.3. Instrument 3 – CRAIC QDI2010

The CRAIC QDI2010 is currently used by law enforcement for forensic casework. CRAIC MSP Data Acquisition Software was opened to process the spectra and CRAIC CCD Image Capture (IC) software (DFx41AF02) was used to view the samples.

The optimum integration time was calculated by the instrument at 1913.23 ms. Standard analysis conditions were set with 400 nm to 700 nm selected. Scans to average were set at 20 with the recommended sampling time of 1242.51 ms. The resolution factor (0–15) was set at 4. The video formats had a frame rate of 1280 × 960 at 7.5, 3.75 frames/s. The dynamic range of the ADC was 10 bit and the signal to noise ratio was ADC 9 bit at 25 °C gain 0.

The IC Capture 2.0 was set at 50% live for visualisation. The exposure was set between 1/83 s and 1/120 s for the duration of the data collection. Brightness was set to 63, gain to 300 and auto reference parameter to 690. The colour settings were kept at the optimum values with hue 181, saturation 129 and white balance auto was selected. The image parameter was set at gamma 12.

2.4. Fingermark exemplar material

The experimental fingermark samples consisted of an inked depletion series which was used in all microspectrophotometric data acquisition. Inked fingermarks were used due to the time lapse between data collection from each instrument and ink deposition was considered a more stable material than other fingermark development methods (e.g. ninhydrin, amido black, physical developer). The depletion series provided samples of differing contrast across a range of depletions between each sample group.

The inked fingermarks were deposited onto Fuji Xerox Performer+® copy paper using a finger loaded with a Lightning Powder Company Incorporation® black Porelon Fingerprint Pad. The male donor freshly loaded the finger in ink and then rolled the finger onto the copy paper, ensuring a fully deposited mark was deposited using a rolled nail-to-nail technique. The thumb was freshly inked and then consecutively deposited three times without re-inking to produce three depletions. This was repeated 30 times with a total of 90 different fingermarks (30 each group). The sample fingermarks were labelled according to deposition with the first known as the n_1 depletion, followed by the n_2 depletion and then the n_3 depletion (Fig. 2).

The inked samples were then stored in Camerons Premium® blank envelopes to avoid any fading caused by ultraviolet radiation and further stored in an insulated Valuca Pty Ltd. Arctic 4L Styrofoam cooler to maintain consistent temperature and enhance the archival considerations.

2.5. Reference standard and control

A mini GretagMacbeth ColorChecker® colour rendition test chart was used as a reference standard and control which consists of twenty-four colour patches of

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Table 1
Results from literature survey regarding methods of articulating fingermark enhancement results.

	Enhancement research	Fingermark image\s	Visual assessment	Visual comparison	Visual score assigned	Side-by-side comparison	Development time	Production cost	Number of marks developed	Quantification attempted	Type of quantification
Reagent	[2]	0	U	●							
	[3]	5	U	●			●				
	[4]	2	U	●	●	●	●		●		
	[5]	3	U	●						●	Spectra
	[6]	5	U	●		●				●	Spectra
	[7]	6	U	●		●		●		●	Spectra, amino acid test
	[8]	0	U	●						●	Spectra, NMR spectra
	[9]	0	U						●	●	Spectra, fluorescence intensity
	[10]	12	U	●		●				●	Spectrum
	[11]	13	U	●		●				●	Amino acid test
	[12]	0	U		●						
	[13]	6	U	●	●						
	[14]	12	U	●	●	●					
	[15]	25	NC	●		●		●	●		
MD	[16]	9	U	●		●	●	●			
	[17]	5	U							●	Deposition (ICP-MS)
	[18]	22	U	●							
	[19]	7	U							●	Deposition (Densitometry & ICP-MS)
	[20]	15	U	●		●					
	[21]	12	U	●		●	●	●			
Powder	[22]	11	U	●		●				●	Spectra
	[23]	3	U	●						●	Weight and volume percent
	[24]	16	U	●						●	Spectra
	[25]	8	NC	●		●				●	Spectra, fluorescence intensity, lifetime
	[26]	17	U	●							
Blood	[27]	8	D	●		●				●	Minutiae counted
	[28]	5	D	●	●	●	●	●	●	●	% Success rate
	[29]	6	U	●	●	●					
	[30]	0	U	●		●					
	[31]	22	U	●		●		●		●	Spectra
Other	[32]	2	U								
	[33]	2	U		●					●	Cyanoacrylate deposition
	[34]	6	U							●	Spectra
	[35]	0	U								
	[36]	16	U								
	[37]	8	U						●	●	Spectra
	[38]	5	NC	●							
	[39]	4	NC		●		●				
	[40]	10	U								
	[41]	34	U	●		●					
	[42]	3	U	●						●	Sputter time, spectra, surface analysis
	[43]	2	D								
	[44]	18	U	●		●					
	[45]	21	D	●		●			●	●	pH testing, Ca spectra, % success rate
	[46]	16	NC								

Visual assessment key, D = Defined, U = Undefined, NC = Not clear.

known colour and reflective values. This study used only the six monochrome references considered as a grey scale of known reflective values. The grey scale consisted of black, white and four shades of grey (Fig. 3). Forty random measurements were taken from each reference standard patch. Data was then analysed to ensure the microspectrophotometers were producing comparable results for the reference standards.

2.6. Data collection and analysis

All data collection parameters were maintained upon the specific instrument for the entire sample collection period to ensure consistency. Each fingermark sample had ten valley readings and ten ridge readings taken on each instrument per group. These spectra were then imported into Microsoft® Excel and this

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Fig. 2. Inked fingermark depletion sample.

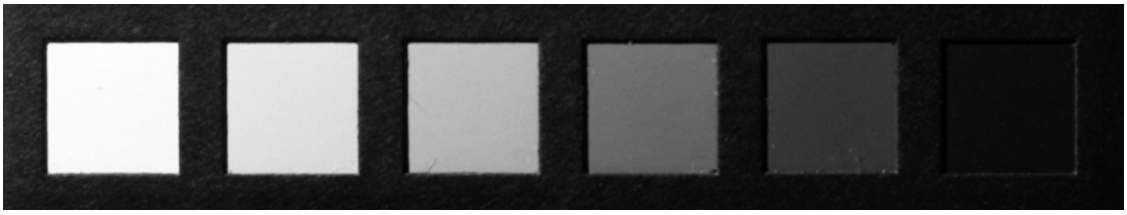

Fig. 3. Gretag Macbeth Color Checker® reference standard.

software was used to construct the relative contrast indices and conduct statistical analysis.

The relative contrast index model analysed the spectral data produced in 'scope' mode. The data analysis used the spectral data determined by integrating the area under the curve [47]. It was considered that averaging the 'percentage reflection' spectral data might be a more meaningful way of analysing the linear response. However, it should be noted that coloured values do not produce a similar curve response.

The data obtained in the visible region was integrated (with values below 3% omitted as white noise) and then compared to the same data mean values (averaging). The raw numerical values were considerably different (Table 2). However, when these values were entered into the relative contrast index formula the results were identical. These results demonstrate that either data analysis method can be used to enter into the relative contrast index formula. A one way ANOVA was completed on the depletion series samples to determine whether the relative contrast index could be used to distinguish between each depletion group (n_1, n_2, n_3).

3. Results

3.1. Reference standard

Each grey value from the reference standard was measured and discriminated according to the different tonal values. However, equivalent percentage reflection values were not achieved from the three experimental instruments (Fig. 4). Instrument 2 almost halved the relative contrast index values obtained per grey tone. Contrastingly, Instrument 1 and 3 decreased more gradually.

3.2. Fingermark exemplar samples

The n_1 depletion produced the highest relative contrast index, n_2 depletion produced the second highest values and n_3 depletion the third (Fig. 5). All three instruments exhibited this trend. There was no overlap observed between the deviations of the different depletions on any of the instruments (Table 3). The data spread reduces similarly from n_1 depletion to n_3 depletion, with the data spread most in the n_1 depletion, less in the n_2 depletion and least in the n_3 depletion which represents a lowering of contrast.

One way ANOVA analysis of the results indicated there was a significant difference between the mean RCI values of Instruments 1, 2 and 3 for each depletion series (Instrument 1, $F_{2,87} = 367.4$, $P < 0.0001$; Instrument 2, $F_{2,87} = 262.2$, $P < 0.0001$ and Instrument 3, $F_{2,87} = 437.3$, $P < 0.0001$). There was also a significant difference between the means of the n_1 depletion, n_2 depletion and n_3 depletion on each instrument (n_1 depletion, $F_{2,87} = 86.5$, $P < 0.0001$; n_2 depletion, $F_{2,87} = 115.3$, $P < 0.0001$ and depletion 3, $F_{2,87} = 119.7$, $P < 0.0001$).

Table 2
Relative contrast index results from each fingermark depletion group.

Depletion	Data analysis	Average ridge	Average valley	RCI
n_1	Integration	19035.73	52862.13	0.4436
	Averaging	28.63	79.49	0.4436
n_2	Integration	30520.95	53011.68	0.2398
	Averaging	45.9	79.72	0.2398
n_3	Integration	38098.11	54723.11	0.1573
	Averaging	57.29	82.29	0.1573

4. Discussion

The relative contrast index model was designed to be simple to implement. Irreconcilable differences existed between the instruments that even the relativity of the model could not compensate

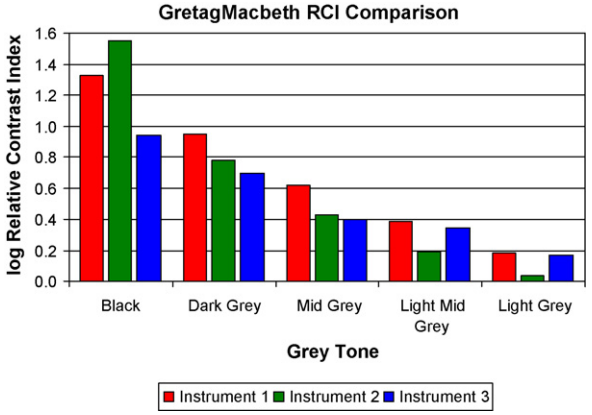

Fig. 4. Relative contrast index values obtained from the reference standard across the instruments.

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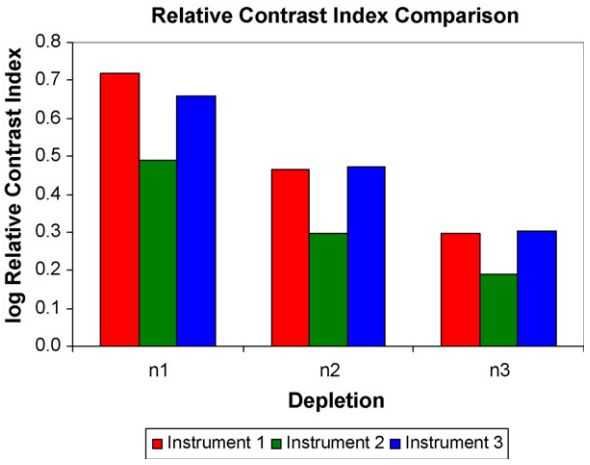

Fig. 5. Relative contrast index comparison of the depletion groups across different instruments.

for. The sampling aperture, operating software and instrument sensitivities perhaps played the key roles in the different results. Technological improvements in the instrument's design and calibration may compensate for these differences in future. However, current instruments though are somewhat incompatible, which is also evident with different spectral libraries for each different microspectrophotometer, suggesting that the instrumentation cannot produce one standard spectral library [48]. The instruments are capable of comparing samples upon the one instrument but cannot read differences the same way across instruments.

The relative contrast index model was found not to produce universal results across the different instruments. The results did not translate into a universal numerical index, such as contrast index models used in photography as measured by densitometers [49]. This was an important development for the model, however, it does not limit its application to the forensic science industry. While the relative contrast index values are not universal across a range of different microspectrophotometers, the results obtained upon the one instrument are still directly comparable. This may provide a quantification of the results obtained from fingermark development research. The comparative results may further be expressed in a percentage of contrast increase or decrease throughout the research results. This empirical quantification may provide a significant advantage when expressing the outcomes of fingermark development and enhancement research.

The application of the relative contrast index and other repeatable quality assessment methodologies could potentially improve the quality of enhancement research by standardising the assessment methodologies and providing benchmarks for current techniques. The relative contrast index also has a potential application for quality assurance of laboratory reagents. Testing prepared formulations to a standard could also allow the discrimination between discoloured or expired reagents.

Table 3
Relative contrast index results from the three instruments used in the experiments made from each fingermark depletions.

Depletion	Instrument	RCI	Standard deviation	Standard error
n_1	1	0.718	0.076	0.014
	2	0.489	0.078	0.014
	3	0.659	0.053	0.01
n_2	1	0.464	0.063	0.012
	2	0.296	0.035	0.006
	3	0.474	0.05	0.009
n_3	1	0.296	0.036	0.007
	2	0.191	0.022	0.004
	3	0.304	0.035	0.006

5. Conclusions

This study has indicated that the relative contrast index model is an effective tool for measuring differences in contrast between fingermark samples. Although, the model did not produce absolute or universal values, it still effectively quantified contrast on each instrument. Identifying the model's applicability to quality assurance in forensic science was also an important outcome. Quantification of fingermark contrast reduces or eliminates ambiguity, as well as providing a documentable, repeatable and objective measurement of contrast enhancement. The relative contrast index model provides a valuable framework and positive outcomes for future forensic science research.

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