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A pilot application study of densitometric image analysis as a potential comparative evaluation method for visualized fingerprints

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Abstract: The current comparison methods with scoring systems that are used to compare visualized latent fingerprints (LF) have disadvantages. Evaluators using these methods are prone to make errors and fail to discriminate LFs correctly to notice the differences among those LFs. Therefore, a comparative and quantitative evaluation method that is capable of obtaining more objective and quantitative results is needed. Densitometric image analysis (DIA) is used in other fields as a reliable semi-quantitative comparison method. To apply DIA to LFs, the potential variables that can occur during the DIA process were tested. The visualized ridges of LFs can be compared using the concentration of dots against the background to make it possible to analyze the ridges with DIA. The variables that can be present during the DIA process include the thickness of the analysis line, the number of ridges to be taken, the number of divided zones within each of the fingerprints, and the angles of the analysis line against the ridge lines that were selected. From the analysis of the inked fingerprints and circular lines that are similar to fingerprints, the angle of the analysis lines with the ridge line was the most significant variable. The preliminary test result was applied to the comparison of LFs that were developed with the powder method and then compared with the AFIS analysis. A similar trend was found, and a more detailed and semi-quantitative comparison of the visualized LFs was possible. In the future, it is necessary to check the evaluative ability of the DIA method by analyzing the visualized LFs with other various development methods. However, DIA is currently an option that can be used as an objective comparative evaluation method during fingerprint studies with supplementary role.

Key words: fingerprint comparison and evaluation method, densitometric image analysis

1. Introduction

Among the plethora of evidence found at crime scenes, substances containing fingerprints and DNA are very important pieces of evidence that allow individuals involved in the incident to be identified.[1] Fingerprint development and identification are some of the most important processes used by crime scene

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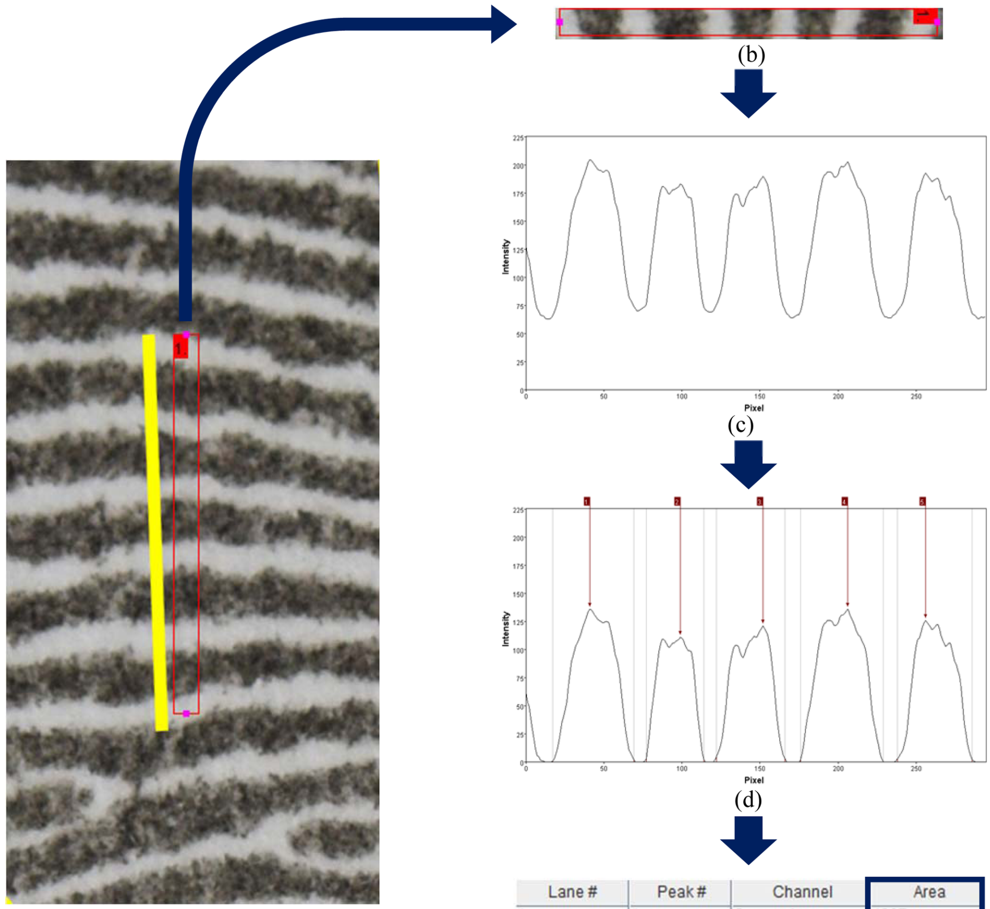
investigators to gather evidence. These techniques are faster and more economical than using the method of DNA analysis.

Fingerprints that are usually found in the field exist in the form of latent fingerprints (LFs) that are difficult to see with the naked eye. Therefore, the most suitable and appropriate visualization method is required and determined by the surface and environment in which the fingerprints are found.[2,3] There are many various, well-known development methods for this purpose that are still being studied as they are gradually evolving.[4] Also, there are diverse methods for the development of the fingerprint left on the same substrate of surface and with the same condition. The comparison and thorough verification between these methods are very important in the area of fingerprint research.[5]

It is necessary to thoroughly compare the quality and integrity of various techniques/technology in order to discover new or modify development methods that complement or replace those techniques/technology. However, in the case of fingerprint studies, it is almost impossible to obtain samples of the same fingerprint under the same condition.[6] Therefore, it is necessary to perform experiments with as many similar fingerprint samples as possible. The low reproducibility of this fingerprint experiment is a well-known issue.[7,8] And the results must use statistically significant quantities of similar fingerprint samples in order to be compared and verified.[9] Comparisons of minutiae that were initially used as mutual comparisons of multiple results are already known to lack justification as a comparison method,[10-12] so several quantitative scoring methods devised by several researchers are currently being used. They are largely used in three different quantification methods, each of which has a different practical purpose as well as advantages and disadvantages. First, McLaren's method mainly compares the left and right halves of split fingerprints that were developed by different methods. When there is no difference between them, it is quantified as 0 points. It is quantified as +1 point for slightly better and +2 points for more excellent visualization. Mainly, the evaluation is done by the naked eye, so there can be discrepancies between evaluators.[13] In addition, since the score for each evaluation unit is very low, a serious error can occur if a small difference is judged to be big. The method by the Center for Applied Science & Technology (CAST) is a method that involves giving a score from 0 to 4, and that score is quantified in about 1/3 units as a whole portion of the clear ridge detail.[14] The modified version of the scoring method is also quantified in units of 1/3, according to the continuous ridges.[15] In the two methods described above, the points are determined by the naked eye according to the clarity and continuity of the ridges. Although they are applicable to whole fingerprints, they are not objective based on subjective observations by the individual's decision under the naked eye. The range of the scoring steps is also narrow. Other evaluation methods are marked with +, ±, or −, using the naked eye and mainly depend on the two-level sharpness of the ridges (minutiae can be observed).[16] Most of these known fingerprint evaluation methods rely on an individual's visual determination of the quality of the fingerprints, so errors are prone to be made, depending on the scorer's experience, expertise, experimentation and training. In particular, according to a recent paper, the method of giving a score of 0 to 4 showed that the score given to each visualized fingerprint by about 67 % of evaluators showed a median grade, and about 99 % existed within the 1 point range.[17] However, overall, this absolute scoring system requires a new evaluation system because the width (0 to 4) of the score range is narrow. Additionally, there is a high possibility of personal error depending on the scorer's experience of evaluating fingerprints. Therefore, there is a need for a quantitative evaluation and comparison method that can complement the problems generated from the scoring systems used until recently. Also, there is a need for a consistent and reliable analysis method that can be used as a quantitative comparison and evaluation method for the various fingerprint development procedures.

Densitometric image analysis (DIA) is a well-known analytical method in biological and chemical research. DIA usually analyzes bands that are separated by



(a)

Lane #	Peak #	Channel	Area
1.	1.	Greyscale	4307
1.	2.	Greyscale	3000
1.	3.	Greyscale	3470
1.	4.	Greyscale	4713
1.	5.	Greyscale	3798

(e)

Fig. 1. The step-by-step flow of densitometric image analysis (DIA) of an inked fingerprint with a yellow reference line and a red analysis line (a), the band that was selected (b), a generated graph of peaks from the selected band (c), a graph with selected peaks and the values of area converted from the selected peaks.

electrophoresis of biological materials (protein, DNA, etc.) semi-quantitatively, quickly and easily according to the degree of concentration that is converted from the bands which is based on the density of dots against the background.[18-20] When the DIA method is applied to a visualized latent fingerprint with similar development method, the selected ridges of the fingerprint with the analysis line have a band with different concentrations against the background (*Fig.* 1). When this band (*Fig.* 1(b)) is analyzed with DIA, the density of the selected fingerprint ridges contrast to the background is expressed as a value of image density that is converted in the form of a peak (*Fig.* 1(c)). This is done so that the area value of each peak can be selectively obtained (*Fig.* 1(d)). The lines that are clear and strong against the background show high area values, and the lines with a weak concentration of dots compared to the background show low area values (*Fig.* 1(e)). Through this principle, it has been reported that semi-quantitative evaluation of the visualized fingerprint is possible by comparing the area values of the selected peaks

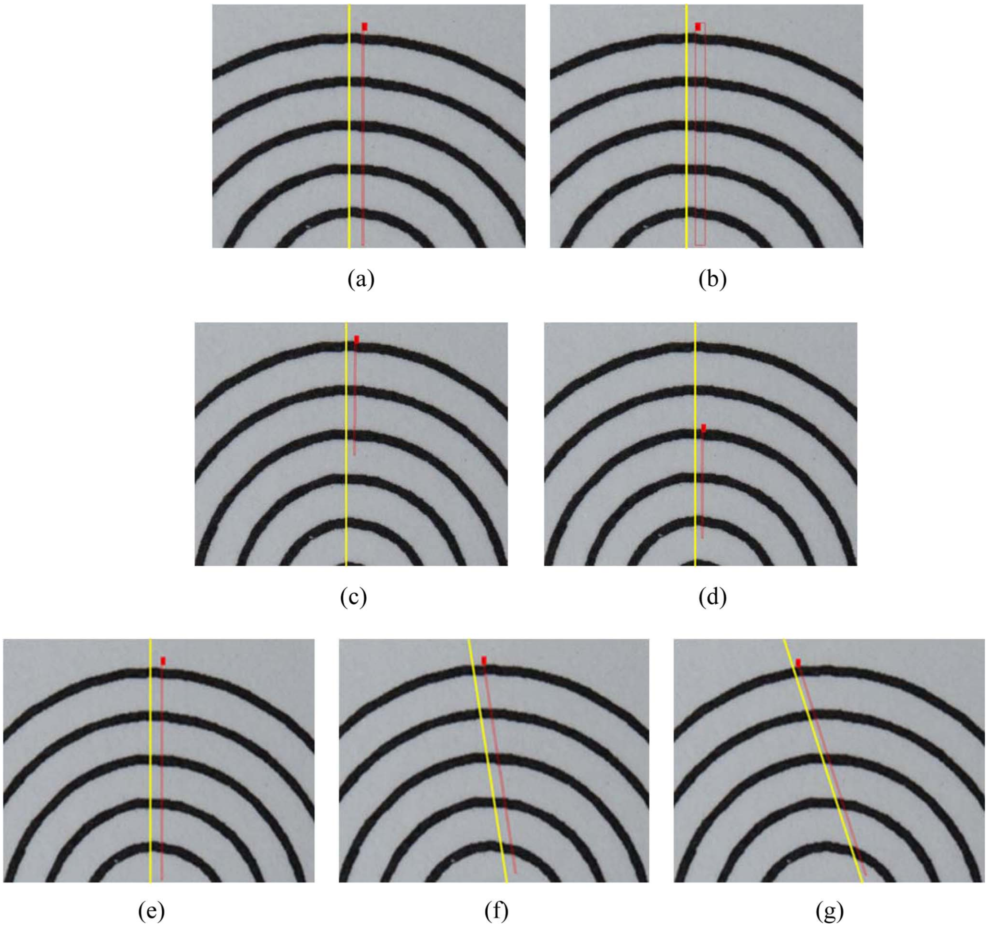


Fig. 2. Reference line (standard line, yellow) and analysis line (red) according to variables (e.g. circle) such as thin (a) and thick (b) analysis line, external (c) and internal analysis line (d), and angle 90º (e), 80º (f), and 70º (g) acquisition against ridges.

converted from the ridges.[21,22]

However, this DIA method has not been verified through general requirements of analysis for its use. Therefore, it is necessary to confirm the specific parameters for consistency and reliability using DIA. That is, in actual operation, when an evaluator analyzes LFs developed with similar visualization technique using an analytical line in the DIA program, there may be variables such as the number of ridge lines taken from the image of fingerprints, their thickness of selected ridges, the angle of the analysis line against the ridges and the number of zones taken from the overall fingerprint image, etc. (*Fig.* 2, 3). Since these variables can fluctuate the result, it is

(a) (b)

Fig. 3. The inked fingerprints with yellow reference lines to show the division of zones: 4 zones (a) and 8 zones (b).

Fig. 4. The circle (left image), ellipse 1 (middle) and 2 (right) used in the densitometric image analysis (DIA).

necessary to verify possible variables generated from the actual operation of DIA.

Therefore, this study aimed to test possible variables using curved lines of prototype fingerprint-like lines first (*Fig.* 4). Then, based on the results with prototype lines, it was applied to inked fingerprints and developed LFs; prior verification was done as an attempt to identify potential parameters in fingerprint analysis through densitometric image analysis (DIA).

2. Materials and Methods

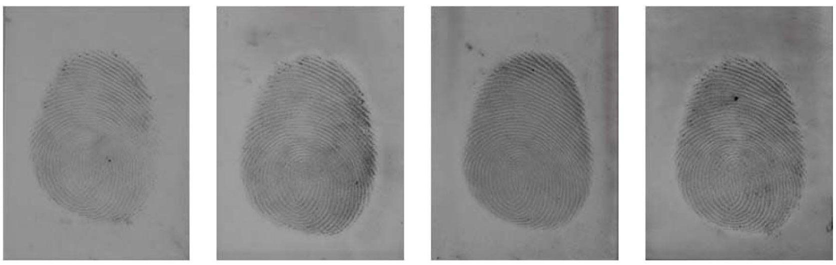
2.1. Sample preparation

Before the actual visualized LFs were used to test the selected parameters such as the number of ridges to be taken, the thickness of the selected ridges, etc., several prototypical lines like the shape of the fingerprint were used. A half of a basic circle and halves of two ellipses with different eccentricity were used as samples by drawing lines with the same thickness and spacing (*Fig.* 4).

In order to compare and apply the basic analysis results using prototype lines to actual fingerprints, two images of inked fingerprints, each of which was strongly and weakly left on a paper with the same finger, were prepared as sample fingerprints (*Fig.* 5). These two inked fingerprints were actually used as the 1st and 2nd fingerprint in a depletion series. In addition, the LFs of the same finger used for the inked fingerprint were developed by the powder-brush method to randomly select for visualized LFs that showed similar or different intensity of ridges by visual observations (*Fig.* 6).

(a) (b)

Fig. 5. Inked fingerprints used for the analysis, strong fingerprint (a) and weak fingerprint (b).



F1 F2 F3 F4

Fig. 6. Latent fingerprints developed by the powder-brush method.

2.2. Experimental methods

The prototype lines used in the experiment were printed on size A4 (Double A) paper. The inked fingerprint was left on the same paper and the latent fingerprint was left on a glass slide (MARIENFELD, Germany) and developed with a brush (SIRCHIE, USA) and black powder (SIRCHIE, USA). Each sample was photographed using a camera (Nikon D5300, Nikon AF Micro Nikkor 60 mm f/2.8D). Then, the image was corrected and a reference line was inserted using Photoshop CS6 (Adobe system Inc.). The resulting image was subjected to densitometer image analysis using CP Atlas 2.0 (Lazarsoftware) to obtain the area values of the peaks that were converted from the selected ridges for each analysis line. The obtained area values were statistically analyzed using Excel 2016 (Microsoft) and SigmaPlot10 (Systat Software Inc.).

2.3. Analysis methods

A total of 3 forms of images that included two ellipses and a circle as well as inked fingerprints and developed LFs was tested using DIA. Each image was analyzed using CP Atlas 2.0, which can be downloaded from the Internet and used. Based on the previously inserted reference lines for each purpose (4 zones and 8 zones selection, *Fig.* 3), bands of ridges were acquired using analytical lines (*Fig.* 1(b)) as follows: 1) The thickness of ridges was controlled with an analysis line from the program where the thickness was approximately 3 times thicker than the thin thickness (*Fig*. 2(a), (b)). Each area value was compared according to 2) the number of acquired ridges (3 and 5), 3) the position of the acquiring lines (analysis lines) was at the inside and outside from the core of the fingerprint, and 4) the acquired angles between the analysis line and the tangent line to the ridge (*Fig.* 2).

3. Results and Discussion

This preliminary study attempted to test and determine the variable factors that would be generated during the process of DIA on developed LFs in order to establish reliable and quantitative fingerprint comparison and evaluation methods. A limited analysis was attempted on the number of lines (ridges), angles, thickness on curvature lines, and number of divided parts of the visualized whole fingerprint (*Fig.* 2, 3). As a result, the changes in the average area value were compared through inter comparison after three repetitive trials. In addition, the preliminary verification of the variable factors was applied to determine the degree of severity for the fluctuation of area changes using inked fingerprints. And finally the results were analyzed after applying predetermined variable factors to the actual LFs that were visualized with the powder-brush method. The results of this preliminary study are expected to be helpful in developing a reliable comparison method of the visualized LFs after determining the potential variable factors that may occur during the operation of DIA.

3.1. Comparison of average area values for prototype lines

3.1.1. Comparison of average area values based on thickness

First, the thickness of the lines taken with the analysis line was tested by putting the lines into two categories (thin and thick) while fixing other variable factors such as the acquisition angle to 90°, five ridges, the external part, etc. Then the changes in the average area values were compared. In actual operation, taking the same thickness of the selected lines with the analysis line was difficult because of the program setting. Therefore, in general, the thick thickness was roughly three times that of the thin thickness (*Fig.* 2). However, if a different number of parts are taken from the same fingerprint, these variables are calculated in the form of a sum of many lines; so there is a possibility of increasing the fluctuation range of the numerical values. In addition, since the ridges of the actual fingerprints do not maintain a constant thickness, unlike the drawn prototype lines, there may be higher fluctuations depending on the obtained thickness.

The difference in the average area values based on the line thickness of the circle was 0.64 %, which indicated similarity, so the change in the thickness of the acquired circular lines could be ignored due to that similarity (*Fig.* 7). Also, the differences between the average area values of ellipse 1 and ellipse 2 were 3.43 % and 3.86 % respectively. It was found that the area value differed with respect to the obtained thickness according to the eccentricity of the circle. In the case of the ellipse, the average area value was slightly larger when the thickness of the selected lines was thick; but it was similar within the error range, so the influence of the acquired thickness as a variable was determined to be insignificant. However, when taking the mixed thickness (thin or thick), the difference can accumulate. It is predicted that the differences of the value will increase, so it is considered that selecting the lines as close as possible to the same thickness as the analysis line will have little effect on the result. In actual operation of the DIA program, it is impossible to make precise numerical manipulations of the thickness when taking ridges, so it is very difficult to make an absolute comparison of each part. However, it is considered that if the experimenter intentionally takes the same thickness, it will not have a significant effect on the results of this study. Therefore, the verification for the other variable factors was compared with the area value set with the same width as the thin thickness.

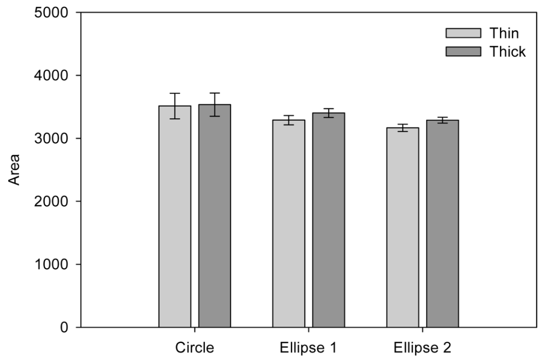


Fig. 7. The results of the average area values of the prototype lines with densitometric image analysis according to thickness.

3.1.2. Comparison of average area values based on the number of ridges, locations and angles

Results were obtained after analyzing the circle, ellipse 1 and ellipse 2 for the number of acquisition lines, the acquisition positions (inside, outside), and the acquisition angles. The average area values for each variable were compared with each other because it was observed that each variable affected each other (*Fig.* 8).

When the analysis line was fixed at 90° for various circular-shaped lines (*Fig.* 2(e)), the differences between the number of lines taken and the acquisition sites were very low, measuring at about 0.1 to 2.5%. However, as the angle decreased (90° → 70°), the area value showed a large fluctuation. This fluctuation was

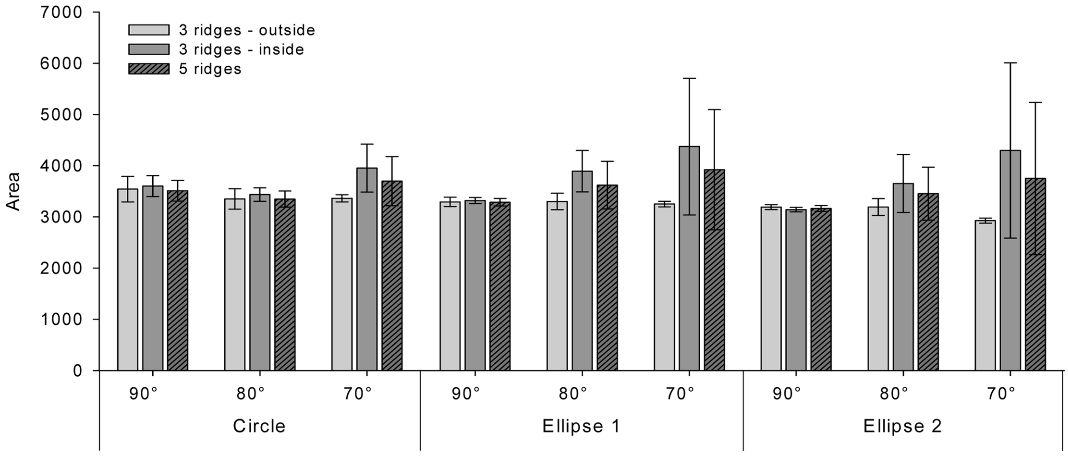


Fig. 8. The results of the average area values of the prototype lines with densitometric image analysis according to the number of ridges, locations and angles of acquisition.

caused by a slight decrease in the area value of the outer lines and a sharp increase in the area value of the inner lines. In particular, when decreasing the angle from 90° to 70°, the area values of the circle, ellipse 1, and ellipse 2 increased by 9.7 %, 31,7 % and 36.7 % respectively, on the inner lines. It was confirmed that this tendency was more pronounced as the degree of distortion of the circle increased, in other words, having greater eccentricity.

As a result of the overall analysis using prototype lines, it was confirmed that the acquisition angle of the ridges was the most important factor when acquiring the ridges with the analysis line. To generate consistent results of the average area values while using DIA reliably, it was found that the acquisition of lines must have maintained the right angle with the analysis line, the acquisition position of the internal or external part must have been fixed, and also the same number of ridges must have been acquired. This is because it was shown that the reliability of the current analysis could be improved by lowering the fluctuation of values according to each acquisition condition with the analysis line.

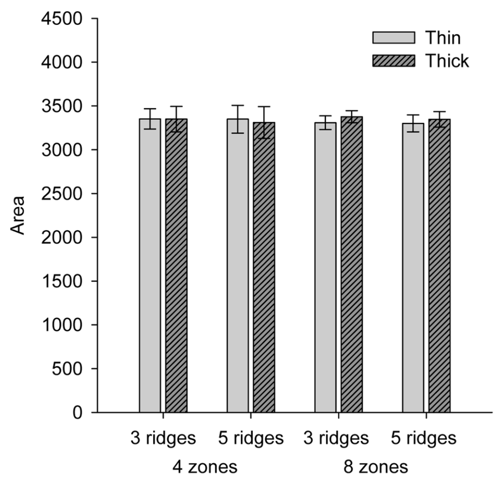
3.2. The comparison of average area values for inked fingerprints

Verification of influencing factors that were found in the DIA results using prototype lines was then attempted by using inked fingerprints that had uniform clarity. This was done in order to evaluate the effects of variable factors such as the thickness, number, and acquisition angle of the ridges. As in *Fig.* 5, inked fingerprints were left strong (a) and weak (b) in the form of a depletion series, and each was analyzed three times. The analyzed ridges were randomly selected for each iteration. The average value and the standard deviation were compared.

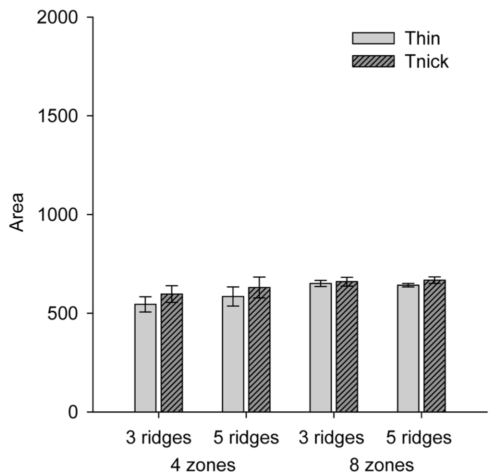
3.2.1. The comparison of average area values by thickness and parts (zones)

When the acquisition angle that acted as the biggest variable found in the prototype line analysis was kept at 90°, the ridges were analyzed to be either thin or thick, and three or five, respectively in order to identify the changes. In addition, since the position of ridge selection from a whole fingerprint is more diverse, the whole fingerprint is roughly divided into 4 zones and 8 zones (*Fig*. 3). The results are shown in *Fig*. 9. The whole DIA process was repeated in the same process as described above to confirm the change.

In the case of strong and clear fingerprints, there was no great difficulty in the DIA operation when selecting the ridges. The distinction from the



(a)



(b)

Fig. 9. Comparison of average area values based on the thickness, number of ridges and number of zones from inked fingerprints, strong (a) and weak (b) fingerprints.

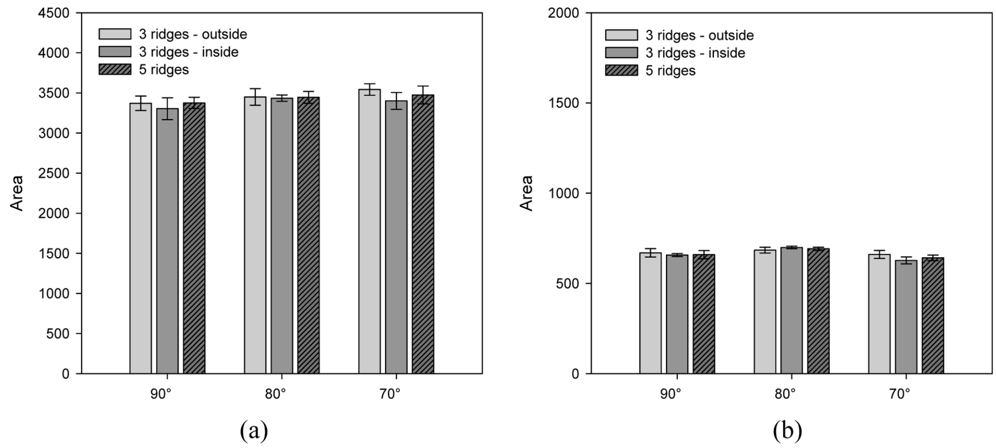


Fig. 10. The changes of the average area values of the ridges according to the number, location and acquisition angle using inked fingerprints, strong (a) and weak (b) fingerprints.

background was clear, so there were no significant differences in the average area values according to the thickness, the number of ridges and the number of zones (*Fig.* 9(a)). However, in the weak fingerprint, the distinction between the background and the ridge was not clear. The noise was difficult to distinguish from the ridges, so the average area values were somewhat changed. The results of the 4 zones - 3 ridges and the 8 zones - 5 ridges showed a difference of about 15 %. The standard deviation decreased by about 78 %, indicating that the variation in average area values tended to stabilize as the number of ridges that were selected were larger. Although it may be more economical to analyze visualized clear LFs by viewing them with the naked eye, it is considered that analyzing many ridges from different areas of the whole fingerprint is a way to reduce analysis errors. Based on these results, the influence of acquisition angles was compared with the other variable factors as the number of ridges (3 and 5) and the position (inner and outer), while the number of zones was fixed at 8 and the thickness as thin (*Fig.* 10).

3.2.2. The comparison of average area values based on the change of the acquisition angle

As a result of analyzing the prototype lines, the difference between the acquisition angles, the number of ridges, and the inner and outer positions from the core, it was found that they had a big influence on the results. The same was applied for the analysis of inked fingerprints.

The tendency of a slight increase in the average area values from the analysis of the outer position to the core of the strongly visualized inked fingerprint was shown when the acquisition angle was decreased. The weakly visualized inked fingerprint showed a mixed tendency of increases and decreases regardless of the number of ridges taken (*Fig.* 10(b)). The average area values of strong fingerprints tended to increase slightly, depending on the angle but regardless of whether it was the inner or outer part of the fingerprint. However, the weak fingerprint showed an inconsistent tendency, demonstrating increasing and decreasing values due to the errors that might have been caused by the condition of the fingerprint. Also the differences were found to be between 2~10 %. It was difficult to maintain and fix a certain angle for the analysis line with the naked eye when performing DIA with a weakly visible fingerprint as this required more time and energy during the DIA process. But it was confirmed that the average area values did not change significantly from the small changes of acquisition angle that were difficult to control and maintain with naked eye. Therefore, the errors from the DIA of the weakly distinguishable fingerprints based on the small changes of acquisition angles are expected to be insignificant. Additionally, it is considered that more accurate results can be obtained if the acquisition angles are as similar as possible in the DIA.

3.3. The comparison of average area values for LFs developed with powder-brush method

Based on the results of the DIA analysis with the prototype lines and inked fingerprints that were conducted earlier, the optimal setting conditions of DIA found for each variable factor were selected as 8 zones, 5 ridges, and 90°. With these conditions set, DIA was repeated three times on the visualized LFs with powder-brush method (*Fig*. 6). The results were also compared with the identified number of minutiae after AFIS analysis (*Fig*. 11).

As shown in *Fig*. 11, the results of the minutiae and average area values of each of the LFs (F 1 ~ 4) showed a similar increase and overall the same graph shape. This was expected to be able to predict the close relationship between AFIS analysis and DIA results, and confirmed the possibility of DIA to be used for fingerprint comparison for future studies. Furthermore, when looking at the differences in the result values range, the number of minutiae increased by 5.88 %, 1.85 % and 10.91 % respectively, but the average area values increased by 58.03 %, 11.27 % and 23.87 %. That is, when comparing the difference between fingerprints with relatively poor quality, the feature point may find it difficult to finely distinguish

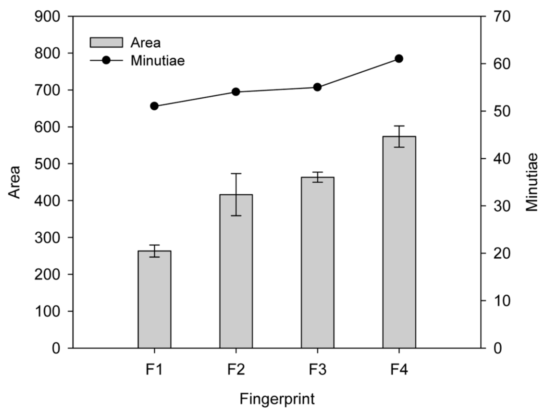


Fig. 11. Comparison of average area values after DIA and minutiae from AFIS analysis with latent fingerprints developed by the powder-brush method.

the quality of the fingerprint with a low percentage difference. However, densitometric image analysis (DIA) is considered to have the ability to classify and confirm more detailed differences according to the quality of the fingerprint since the difference in the rate of change of the average area values is greater.

4. Conclusions

In order to evaluate densitometric image analysis (DIA) as a potential quantitative evaluation and comparison method for fingerprints, images of prototype circular lines, inked fingerprints and latent fingerprints developed by the powder-brush method were analyzed based on the expected various variable factors. The thickness, the position and number of ridges to be taken, the acquisition angles of the ridges with the analysis line and the number of zones of the whole fingerprint to be analyzed were tested as variables.

Prior to introducing DIA into the actual fingerprints, each of the variable factors were analyzed by applying them to prototype circular lines similar to that of the real fingerprint. As a result, the average area values were greatly influenced as the acquisition angle between the analysis line and ridges changed. But when the angle was kept near constant, the changes in thickness and number of ridges were insignificant.

As a result of analyzing the strong and weak fingerprints left by ink, the differences in the thickness, number of ridges and the area of the fingerprint were not significant in the case of the strong fingerprints. In the case of the weak fingerprints, the quality status of the fingerprint was somewhat difficult to analyze, so the deviation tended to increase. However, as the number of analyses increased, the area value increased slightly, and the error tended to decrease. In addition, when looking at the variation in the angle that was a significant variable in circular line analysis, the area values showed inconsistent changes but generally similar values. Therefore, it is considered that the error within the angular range, which is difficult to distinguish with the naked eye, will not significantly affect the results.

The latent fingerprints developed by the powder-brush method were compared in average area values and minutiae using DIA and AFIS analyses. The results showed that the shapes of both graphs were similar, depending on the quality of the fingerprint. This is thought to be the result of confirming the relationship between AFIS and DIA. Also, in comparing the quality of fingerprints, the minutiae of AFIS analysis is that the range of the rate change is low. But in the case of DIA, due to the higher rate change, the quality of fingerprints can be further distinguished although they are difficult to distinguish with the naked eye.

According to the results of this study, the largest variable in the DIA method can be seen as the angle of the analytical line and the ridge. But the angle is also believed to have no significant effect within a certain range. In addition, the results of the analysis tend to be similar to the results of commonly used minutiae of AFIS analysis. They are expected to provide more detailed results in the quality comparison process of the fingerprint, thus confirming its usability as a comparative evaluation method for visualized fingerprints with similar development method.

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