The new method of identification of handwriting using volumes of indentations

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Abstract

Indicators of handwriting examination in recent forensic science are mainly figures on two dimensional planes. However forgeries of handwriting which are over-written on genuine one while being watched through paper aren't able to distinguish from the genuine one. This article tried to use other indicators with regard to pen-tip forces. Pen-tip forces were measured using a digitizer tablet during drawing four directions short lines. Simultaneously volumes of indentations which were pressed by the pen-tip forces were measured using our proposed method of applying shape from shading. The pen-tip forces and the volumes of the indentations were compared with correlation. The results showed both the indicators had high correlations. In addition the patterns of the volumes of the each direction were different between ten subjects. This provides forensic document examiners with a powerful tool which is applied to identifying writers using volumes of indentations of handwriting which composed of four directions short lines.

1. Introduction

Although handwriting is traces of human movements which are planned by their brains and are also performed by their fingers and arms when the humans write characters, handwriting is only dealt with figures on a sheet of paper by forensic document examiners and scientists of computational forensics using image processing. In this article, it was thought that handwriting was not only images on two dimensional planes but also traces contained hidden useful information in three dimensions such as indentations. In real crime scene, figures of handwriting are easily possible to observe while volumes which were composed of depths and widths of the indentations are difficult to observe by human naked eyes. Consequently, criminals are extremely incapable of forging the volumes of the indentations of handwriting which is written by other persons. This article investigated, therefore, relationships between pen-tip forces and volumes of indentations made by ten subjects. Pen-tip forces which were an indicator of an online method were measured by using a digitizer tablet and a piece of software which controlled the tablet. At the same time, volumes of indentations which were an indicator of an offline method were measured by using our proposed method of applying an optical model called shape from shading. Both the indicators were analyzed by using analysis of variance (ANOVA) and Pearson's correlation. In addition, patterns of the volumes of each four writing direction between the subjects were investigated. It was, as a result, found that each subject showed the unique pattern of the volumes between the four writing directions. This provides forensic document examiners with a powerful tool which is applied to identifying writers using volumes of indentations of handwriting which composed of four directions short lines. Details of above method were described in the following sections.

2. Method

This article tried to make experiments in order to investigate relationships between pen-tip forces and volumes of indentations by the following procedures. At first, pen-tip forces were measured while subjects drew short lines using a digitizer tablet. Secondly widths of indentations made by the pen-tip forces were measured using a measurement micro scope. Subsequently depths of the indentations were constructed from images captured with Near Infrared (NIR) Complementary Metal-

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Figure 1. Experiment situation

Table 1. Digitizer tablet specification

Items	Specifications
Maker	WACOM
Model	Intuos 2:XD-0912-U
Resolution	Up to 2,540 lpi
Frequency of sampling	100Hz (Max 200Hz)
Sensitivity of pressure	1,024 levels

Table 2. NIR LED illuminator specification

Items	Specifications
Maker	HAYASHI WATCH-WORKS
Product name	NIR light emitting diode
Model number	HDMISI8IR-940
Central wave length	940nm

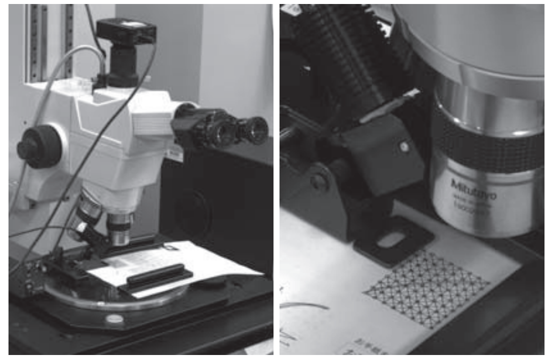
Table 3. NIR CMOS camera specification

Items	Specifications
Maker	Lumenera corporation, Canada
Model number	Lu105M-IO-WOIR
Resolution	1280x1024
Density	8 bits
Pixel size	5.2 μ m x 5.2 μ m

oxide Semiconductor (CMOS) camera under oblique illumination using a NIR Laser Emitting Diode (LED) and an optical model called shape from shading. Later on volumes of the indentations were obtained by being multiplied the widths by the depths of indentations. Finally the pen-tip forces and the volumes of indentations were compared.

2.1. Subjects

Seven right-handed males, two right-handed females and one left-handed male, with an average age of 30.5 years, participated in the experiment. The purposes of the experiment (i.e., ”pen-tip force” or ”pen-tip positions” were measured) were explained to the subjects.



(a) (b)

Figure 2. Overview of the equipment which measured indentations of short lines. (a) is the microscope with the CMOS camera. (b) a is the NIR LED.

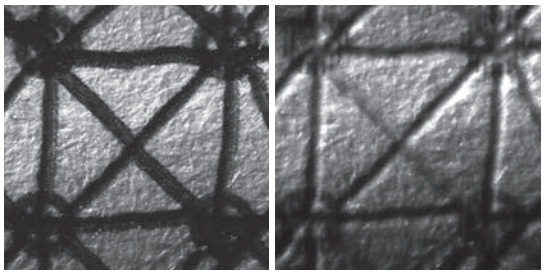
2.2. Tasks

The subjects were asked to sequentially draw short lines which connected two circles and those writing directions were vertical, horizontal, right-down, and left-down on a sheet of paper which was attached on the following digitizer tablet. The circles whose diameter was approximate 1mm were printed by a laser printer. The circles were arranged in orderly nine columns and eight rows. A number of iteration, hence, was sixty four during drawing lines along vertical direction. A number of iteration was sixty three during drawing lines along horizontal direction. A number of iteration was fifty six during drawing lines along right and left down directions. The vertical and horizontal length between the circles was approximate 4mm.

2.3. Materials

2.3.1. Digitizer tablet and software. Table 1 showed the specifications of the digitizer tablet used in the experiment. In this article a QDEware which was developed by National Research Institute of Police Science (NRIPS, Japan) was used. The QDEware was able to obtain the data of pen-tip forces and x-y coordinates from the tablet.

2.3.2. NIR LED and CMOS camera. As shown in Figure 2, a measurement microscope (MF-UD3017B, Mitutoyo, Japan) with a NIR long pass filter (Wratten No.87C, Kodak, USA) was used under illuminating by using a NIR LED (HDMIS I8IR-940, HAYASHI WATCH-WORKS, Japan). The specification of NIR



(a) (b)

Figure 3. Magnified images of handwritten lines with a black ink ball point pen. (a) is an image under a visible light illumination. (b) is an image under the NIR LED illumination.

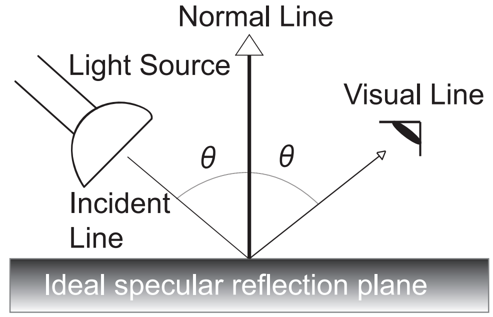


Figure 4. Diagram of Lambert model.

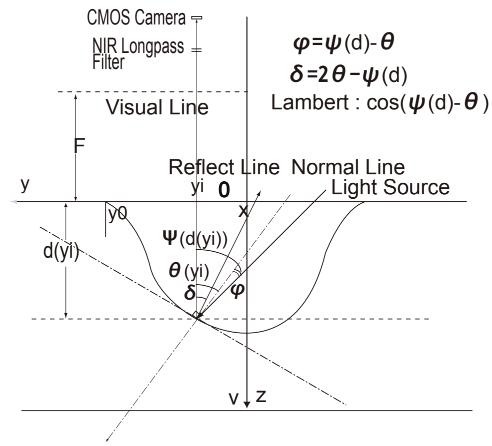


Figure 5. Diagram of Lambert model which applied for the relationship between indentations and oblique NIR LED illuminations.

LED was showed in Table 2. Images which were observed by using the microscope were captured by a NIR CMOS camera (Lu105M-IO-WOIR, Lumenera corporation, Canada) which was attached with the microscope. The specification was showed in Table 3.

2.4. Indicators measured in the experiment

2.4.1. Online indicator measured in the experiment. At first, pen-tip forces were measured. After measured, it was investigated that inter-variance and intra-variance between subjects and between directions. ANOVA was performed to the each indicator of ten subjects.

2.4.2. Offline indicator measured in the experiment. This article selected volumes of indentations of handwritten lines from offline indicators of handwriting. We had already proposed the method which reconstructed depths of indentations from shades image of indentations [3]. Here the several procedures of the method were described briefly. At first, the indentations made by the pen-tip forces were observed under an oblique NIR illumination. The indentations which made when the short lines drawn by a black ink ballpoint pen which was normal attachment of the digitize tablet. We can usually observe indentations as shades are made by a visible light when surfaces of concaves of indentations reflect a visible light which is emitted by illumination. However, it is difficult to distinguish between the shades and black inks of ballpoint pen since both the colors are similar. Consequently, NIR naturally transmits the ballpoint ink that the indentations are more obvious as shown in Figure 3. Depths of indentations were reconstructed from the images captured under oblique NIR LED illumination using shape from shading as shown in Figure 4, 5. We proposed the following equation (1) because indentation profiles were approximated by Gaussian curves as shown in Figure 6.

$$f_{profile}(x) = a \cdot \exp\left(-\frac{x^2}{b^2}\right). \qquad (1)$$

'x' denoted a position along a horizontal axis in indentations, 'a' denoted depths of indentations and 'b' denoted widths of indentations. After Gaussian curves were differentiated tangential lines to the indention profiles were obtained. By being approximated indentation profiles by Gaussian curves and by differentiated this curves tangential lines to indentation profiles were obtained. By inversed tangential lines normal lines were acquired because normal lines were orthogonal to tangential lines. After mentioned above calculations we acquired normal lines and angles between normal lines and the visual lines (see Eq. 2).

$$\theta = \tan^{-1}\left\{-\frac{2a}{b^2}x \cdot \exp\left(-\frac{x^2}{b^2}\right)\right\}. \quad (2)$$

Also angles between NIR LEDs illuminating lines and the normal lines were calculated by below equation (see Figure 4, 5).

$$\phi = \frac{\pi}{4} - \theta. \quad (3)$$

Intensity of brightness on indentations surface was cosine of ϕ. Consequently following function was obtained.

$$f_{intensity}(x) = \frac{\sqrt{2}}{2}(\cos\theta + \sin\theta). \quad (4)$$

As shown in Figure 7 we simulated brightness profiles of handwriting using the NIR LED and the Lambert model. In turn the profile of the indentation was reconstructed from the brightness profile. Consequently, the following estimated function was obtained and it was tried to minimize this function. L was an estimated value. $\bar{F}$ was a real measured data and f was the fitting function descried above in following Eq. 5.

$$L = \left\{\bar{F} - f_{intensity}(x)\right\}^2. \quad (5)$$

The depths of the indentations were shifted from 1 μm to 100 μm. The depths estimated were able to be obtained in this way.

2.4.3. Analysis between online and offline indicators. Online indicators (i.e., pen-tip forces) obtained in this experiment were tested by using ANOVA intra and inter the subjects. And the variances of four directions (i.e., vertical, horizontal, right-down, and left-down) of lines which were drawn by ten subjects were also tested. In addition interaction between the subjects and the directions were calculated using ANOVA. Next, offline indicators (i.e., depths and widths) obtained in this experiment were synthesized to new indicators called volumes. The volumes were multiplied values by the depths and the widths. Finally Pearson's correlation of both the online and the offline indicators which were described above was calculated. To investigate the relationship between the pen-tip forces and the indentations the volumes of each subject were plotted on a graph. The volumes of 2390 lines (10 subjects 4 directions (64(vertical) + 63(horizontal) + 56(right-down) + 56(left-down)) written by the subjects were calculated using Principal Component Analysis (PCA).

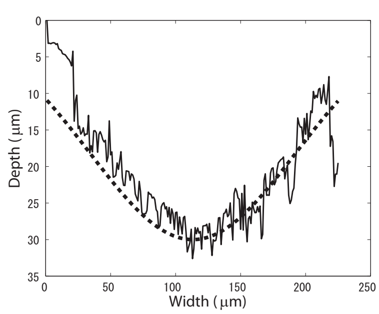


Figure 6. An indentation profile approximated with Gaussian function.

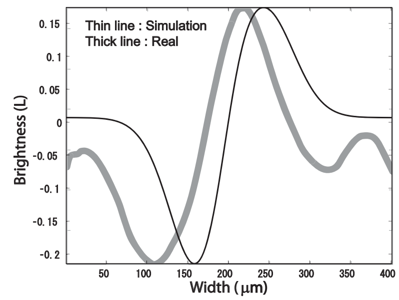


Figure 7. Compared between a simulated brightness profile and a real brightness profile. (a) is a real, (b) is a simulated.

3. Results

Table 4 showed the results of the pen-tip forces which were measured in the experiments during drawing the short lines. At first, we test the variances of the pen-tip forces between the subjects and the variances of the pen-tip forces within each subject using

Table 4. Peaks of pen-tip forces during drawing lines

Sub./Dir.	vertical	horizontal	right-down	left-down
1	0.509	0.659	0.603	0.603
2	0.481	0.540	0.610	0.598
3	0.829	0.879	0.887	0.810
4	0.645	0.751	0.722	0.685
5	0.482	0.421	0.463	0.512
6	0.818	0.843	0.793	0.790
7	0.772	0.816	0.798	0.811
8	0.999	0.999	0.999	0.996
9	0.834	0.854	0.931	0.810
10	0.768	0.756	0.781	0.747

Table 5. Result of ANOVA of pen-tip forces

Factor	Dev.	df	Var.	F
Subject	51.85	9	5.76	1915.73**
Direction	0.67	3	0.22	73.90**
Interaction	2.01	27	0.077	25.57**
Error	6.62	2200	0.003	
Total	61.21	2239		

ANOVA. As well as the subjects, the variances of the directions were also tested. Table 5 showed the result of ANOVA of the pen-tip forces. The variances between the subjects, the directions were significantly lager than the variance within each subject, each direction. This meant that the pen-tip forces were useful for writer identification. Table 6 showed the results of the indicators in the indentations (i.e., depths, widths, and volumes) corresponding to the pen-tip forces during drawing the short lines of the four directions. As same as the pen-tip forces ANOVA of the volumes was calculated. Table 7 showed the result of ANOVA of the volumes. The variances between the subjects, the directions were also significantly lager than the variances within each subject, each direction. In addition, there were the significant differences in the interactions between the subjects and the directions. This meant that the volumes of the indentations were also useful for writer identification. Finally Figure 8 showed the results of comparing both the online and the offline indicators (i.e., the pen-tip forces and the volumes of the indentations). The Pearson's correlation between both the indicators was 0.814. Figure 9 showed the pattern of volumes of each direction between the subjects. The profiles of the volumes of the four directions were different between the ten subjects. Table 8 showed the results of PCA with which the eigenvalues and the eigenvectors of the volumes were calculated in the experiments. We considered that the first eigenvalue indicated

Table 6. The indicators of indentations and pen-tip forces

Sub./Indi.	force	depth	width	volume
1	0.594	49.76	279.88	14219.13
2	0.558	41.07	247.11	10576.05
3	0.851	55.08	281.38	17136.35
4	0.701	49.50	285.69	15055.70
5	0.469	34.11	254.25	8697.15
6	0.811	52.21	303.40	15154.79
7	0.799	52.46	308.86	16131.05
8	0.998	65.13	332.02	22658.85
9	0.857	53.07	313.53	16777.96
10	0.763	46.79	303.70	14269.07

Table 7. Result of ANOVA of volumes of indentations

Factor	Dev.	df	Var.	F
Subject	$2.87e^{10}$	9	$3.19e^{9}$	69.29**
Direction	$1.00e^{10}$	3	$3.34e^{9}$	72.62**
Interaction	$5.11e^{10}$	27	$1.89e^{8}$	4.12**
Error	$1.01e^{11}$	2200	46007760	
Total	$1.45e^{11}$	2239		

the quantities of the volumes of the indentations since all the eigenvectors had positive and the eigenvectors of the first column corresponded to the quantities of the volumes of the indentations of the lines drawn by each subject. The second eigenvalue indicated the flatness of the volumes between the four directions since Table 8 showed that the subject 2 took the largest eigenvector while the subject 4 took the smallest eigenvector and Figure 9 showed the profile of S2 was most flat while that of S4 was most steep. Likewise the third eigenvalue indicated the angle of which was composed plotting the three points (i.e., vertical, horizontal, and right-down) since Table 8 showed that the subject 10 took the largest eigenvector while the subject 3 took the smallest eigenvector and Figure 9 showed the angle of S10 is smallest while that of S3 was largest. Figure 10 showed that the relationship of the three eigenvalues which correspond to the individuality of each subject.

4. Conclusion and future work

We tried to analyze the relationship between the pen-tip forces and the volumes of indentations. The results indicated that both the indicators had the strong corre-

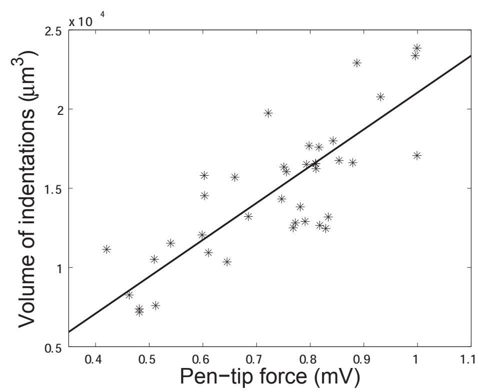


Figure 8. Relationship between pen-tip forces and volumes of indentations

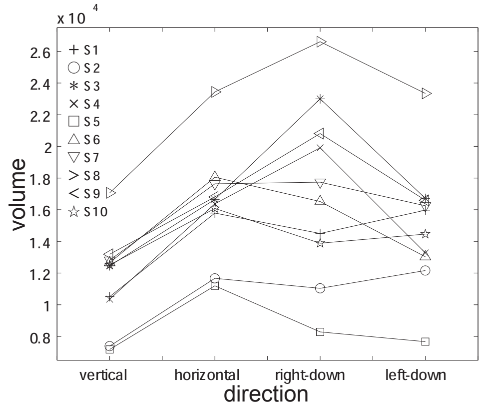


Figure 9. Patterns of volumes of each direction between subjects

lation. In addition, the patterns of the volumes of each direction were different between the subjects. This new finding means that we are going to able to apply the method to identify writers by measuring volumes of indentations of handwriting of which composed the short lines of the four directions (e.g., a Chinese character '木' or an English word 'TAX'). Franke et al. [1-2] reported that the ink density and the pen-tip forces were approximated by cubic function. Our results obtained by using hypothesis which implied both the onine and the offline indicators have a linear regressive relationship. However, it is not sure that both the indicators had the linear relationships since the subjects were only ten in our experiment. We dealt with the short lines which were sequential drawn since the experimental conditions and the analysis were become simple. The advantage of our method was easy to measure the depth of indentations. We used the micro scope with the oblique NIR LED illumination in the study. The advantage of microscopes is high optical resolution while the defect is narrow measurement area. We previously applied a NIR flat bed image scanner for measuring depths of handwritten indentations and spur marks of ink jet printers [4-5]. The advantage of image scanners is wide measurement area while the defect is low optical resolution. Recently a new high resolution scanner with NIR illumination is developed by iMeasure Inc., Japan [6]. We expect forensic document examiners will soon use the new NIR scanner and our method to examine handwriting on questioned documents.

Acknowledgments.

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Table 8. Result of PCA of volumes of indentations

Eigenvalue	1.13E+09	3.35E+07	4.04E+06
Eigenvector S1	0.283	-0.084	0.394
S2	0.296	0.934	-0.166
S3	0.346	-0.192	-0.518
S4	0.302	-0.202	-0.267
S5	0.171	-0.002	0.385
S6	0.301	-0.024	0.254
S7	0.321	-0.062	0.179
S8	0.452	-0.162	-0.053
S9	0.337	-0.106	-0.266
S10	0.282	0.040	0.399

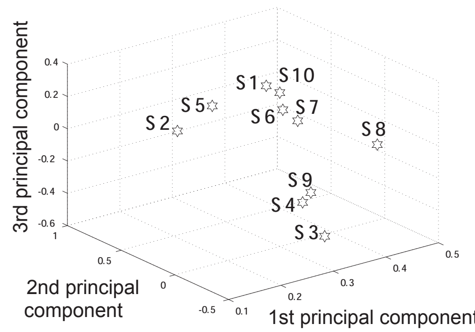

Figure 10. Relationship of eigenvectors between subjects

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