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PAPER

QUESTIONED DOCUMENTS

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Detection of Transcribed Seal Impressions Using 3-D Pressure Traces*

ABSTRACT: Seals have been frequently used to certify that individuals or organizations have authorized or approved a document that bears these impressions. Much attention has been focused on the detection of forged seal impressions to expose and prevent seal-related frauds. This paper describes an image-processing technique that detects seal impressions transferred from a genuine document to a target document using transcription media. The proposed method utilizes a three-dimensional (3-D) scanner to generate a pressure trace map of the suspect seal impression. After utilizing a noise-reduction algorithm to improve image quality, the pressure map is aligned with a 2-D image of the same seal impression. The pressure ratio, determined by comparing the pressure map and inked impression of a suspect seal, can be used to determine whether the seal is genuine or was transferred to the target document. The results show that the proposed technique successfully identified transcribed seal impressions with an error rate of <1%.

KEYWORDS: forensic science, questioned documents, seals, seal impression forgery, transcription, 3-D scanning, pressure trace map, image processing

Seals are widely accepted as a means to certify official documents that are often encountered in business transactions and other types of official agreements. Therefore, it is important to develop reliable methods to determine whether a seal impression is genuine. In many countries, official seal impressions are required to be enrolled with a designated authority. Government agencies often accept registered seal impressions to verify the validity of business and legal documents. Over the past few years, the National Institute of Scientific Investigation in South Korea has received thousands of requests from clients in the private and public sector to investigate the authenticity of seal impressions. The number of such requests continues to increase from 1220 cases in 2007 to 1255 in 2008, 1544 in 2009, and 1896 in 2010 according to National Forensic Services of Korea (1). As a result, the detection and prevention of forged seals has become a priority.

In general, three common approaches have been used to forge seal impressions: (i) producing a fake seal by carving, (ii) lithography, and (iii) transcription. The first method involves producing a seal that can be produced from a photograph or a film negative of an original seal impression, either by hand carving or using computer-aided precision engraving machines. With the lithography method, an original impression is photographed to the same size to create a film mask. The film mask is then put on a metal letterpress plate or a photosensitive resin letterpress plate, and then exposed, corroded, and developed to create a seal impression. The transcription method requires duplicating a seal impression by transferring the inked pattern of an original seal impression to the target document using various transcription media. The media used in the transcription often include paraffin-coated film, laboratory sealing film, chewing gum paper, and even general purpose copier paper when the stamp ink is not completely dry. Paraffin wax is unaffected by the most common chemical reagents, and its hydrophobic property enables easy transcription of seal impression. This method can quickly and easily produce forged seal impressions without the need to use lithography or engraving machines. This method is far more common, and therefore, there has been a need to implement a more systematic approach to perform examinations on forged seal impressions produced by transcription.

The detection of forged seal impressions by transcription has been a challenging task for forensic scientists. A large part of investigation relies on visual inspection. The most common method used in a forensic examination requires the use of magnifying glasses or microscopes for close-up examination of the adhesion state of stamp ink as well as the changes in paper surface caused by friction while changing illumination angles (2,3). With the visual inspection of seal impressions, however, the accuracy varies depending on the operator's skill levels and experience. As transcription may cause some residues of the medium left on the surface of the document bearing a forged impression, a multiwavelength light source or Fourier-transformed infrared spectroscopy and other analyzers can be used to detect the residue of the medium

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(4). Chemical testing methods, however, are not preferably used because they can damage the evidences of transcription onto a paper.

Methods and Materials

When transcription is used to forge seals, a transcription medium is placed on an original seal impression, and then, it is rubbed to let the medium absorb stamp ink remaining on the paper surface. Afterward, the medium is placed on a document, and the transcribed seal is rubbed again to get the seal pattern transferred onto the target document. Figure 1 describes the procedures of a seal impression forgery method by transcription. This method is considered relatively simple and therefore can produce exquisite forged seal impressions. Further, the enclosure and size of the forged seal impression are similar to those of the original impression, making it difficult to distinguish one from the other. Figure 2 shows an example using different types of media such as a paraffin-coated chewing gum paper, a laboratory sealing film, and a copier paper. The transcribed seal impressions contain the features of original seal in reasonably high quality and therefore may be accepted as authentic if they are not properly examined.

This method involves obtaining a three-dimensional (3-D) measurement of a seal impression after it has been impressed onto a document. A high-resolution, optical 3-D scanner (GOM ATOS2®; GOM mbH, Braunschweig, Germany, http://www.gom.com/company/company-profile.html) was used to measure pressure traces of seals imprinted on paper. This device has a spatial resolution of up to 1 micron, which is good enough to obtain the pressure trace pattern of a seal. The pixel resolution of the CCD camera is 1392 × 1040. And the use of narrowband blue light enables precise measurements independently of environmental lighting conditions. Three-dimensional scanners can also help detect traces of the strokes of a signature imprinted on a signature paper as well as on papers placed underneath the signature page (5). After generating a pressure map of a seal impression using a 3-D scanner, the pressure map is aligned with a 2-D image of the seal impression. To enhance a faint pressure trace map, the noise is removed using the distribution of the noise observed in the neighboring region of the seal pattern. The pressure ratio determines the degree to which the sealing pressure trace map matches the inked seal impression. Then, we compare the average pressure ratio of the target seal impression with that of the original to decide whether the seal is transcribed. If the average pressure ratio of the target seal impression is sufficiently close to that of the original seal within a prespecified margin, the seal can be classified as authentic.

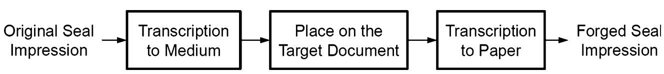

FIG. 1—*The procedures of seal forgery by transcription.*

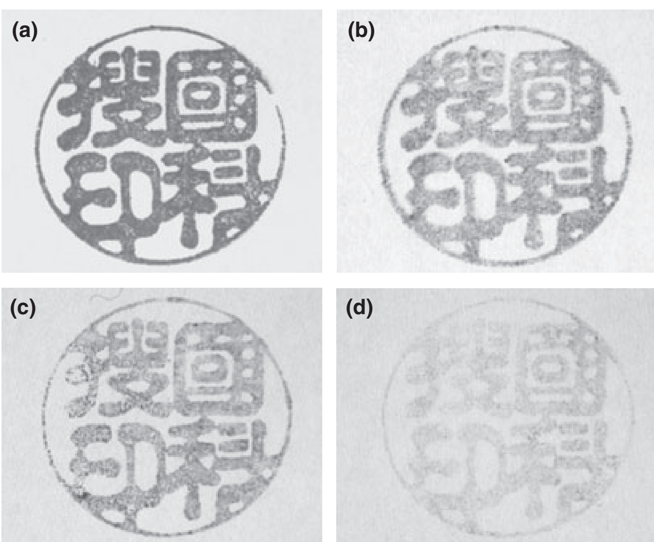

FIG. 2—*Transcribed seal impressions using common transcription materials: (a) original impression, (b) chewing gum paper, (c) laboratory sealing film, and (d) copier paper.*

Measurement of Sealing Pressure Traces Using a 3-D Scanner

A close observation of paper shows that its microstructure contains many air gaps inside. Therefore, sealing on a paper leaves unrecoverable pressure traces. Magnifying the structure of a regular copier paper using scanning electron microscope (SEM) or transmission electron microscope (TEM) reveals that paper consists of lots of pulp fibers (long shape) and filler talc or fine stone powder (round shape). Figure 3 shows magnified microstructures of a paper surface of *c.* the size 450 × 350 μm using an SEM with a magnifying power of 350 (350×) and of a paper cross-section of the size 60 × 50 μm using a TEM (1000×).

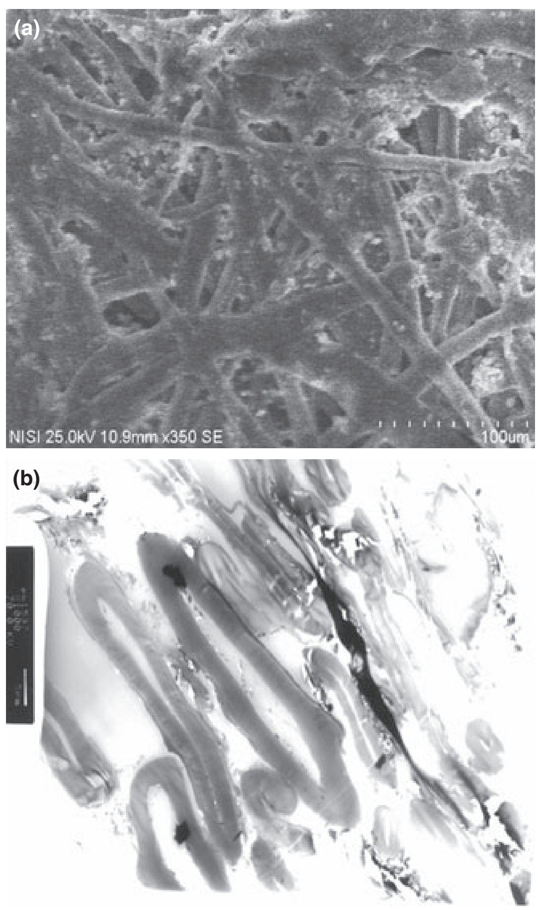

FIG. 3—*Magnified microstructures of a paper: (a) paper surface of the size 450 × 350 μm using the SEM (350×), and (b) paper cross-section of* c. *the size 60 × 50 μm using the TEM (1000×).*

To measure seal pressure traces on the paper, a 3-D scanner is used. Various 3-D measurement techniques, such as atomic force microscopy and 3-D laser profilometry, can also be used to inspect handwriting patterns (6). Three-dimensional scanning techniques involve contact-type scanner, slit beam-type laser scanner, point beam-type laser scanner, time-of-flight laser scanner, and pattern project-type scanner (7–14). Owing to low resolution, contact-type and laser-type scanners may not be appropriate for measuring the seal pressures. In this paper, a pattern project-type scanner is used, which projects fringes on a 3-D object and takes pictures using stereo cameras and computes the difference of the two images to find the depth information (15). Figure 4 shows the appearance of the 3-D scanner used and a pressure trace map of a seal impression in pseudo color. The pressure traces caused by the factors other than the seal itself such as roughness of the paper surface, illumination, and scanner conditions may be measured as a form of noise.

The average sealing pressure is high (16), and a typical sealing area on a paper tends to be in the range of 1 cm^2. In addition, the seal area painted by ink is even smaller than that, thereby a high pressure is locally applied to the inked impression. As a result, the internal structure of the paper is permanently altered by the applied pressure. This makes the pressure mark of a seal impression remain on paper for a long time period. Therefore, sealing pressure can be observed using a 3-D scanner after several years of imprinting. Our experiment shows that pressure trace patterns could be measured after 15 years. Figure 5*a*,*b* shows an original seal impression on a regular copier paper created in 2009 and its pressure trace map measured using the 3-D scanner. Figure 5*c*,*d* shows the same seal imprinted in 1994 as well as its pressure trace.

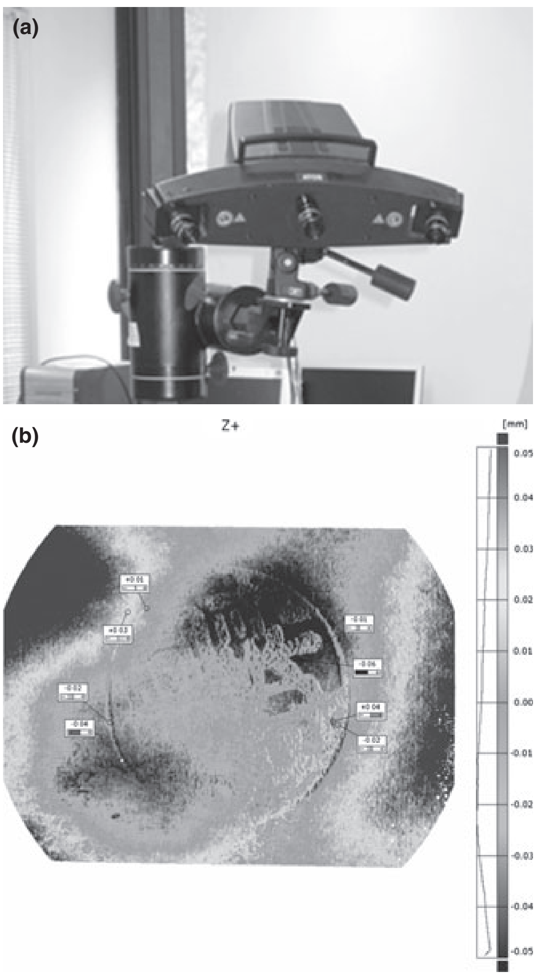

FIG. 4—*Measurement of the 3-D information of a seal impression: (a) a 3-D scanner (GOM ATOS2®), and (b) pressure trace map of a seal impression in pseudo color.*

A pressure trace map captured using a 3-D scanner and a 2-D seal impression image need to be spatially aligned to have the same scale and orientation. We carry out image registration using a rigid body transformation, which involves translation, rotation, and scaling. Four marker points outside the seal impression are used as control points for the registration of rigid body objects. When an image pixel at a spatial coordinate of (x, y) is transformed into a new point (x', y'), the geometric transformation can be expressed as a multiplication of transform matrices with a coordinate vector. If the point is shifted by (x_0, y_0), expanded by the scale s, and rotated counterclockwise by the angle θ, the transformation is expressed as:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & x_0 \\ 0 & 1 & y_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad (1)$$

We can solve the equation to determine the unknown transformation parameters for a given set of reference points. Figure 6 shows a 2-D image and a 3-D pressure trace map of a genuine seal impression that are spatially aligned with each other. The ink portion of the seal is separated from the background using a threshold (17–19) based on the difference between red and green components. The Otsu algorithm (18) was used to find the threshold.

Detection of Transcribed Seal Impressions

In this paper, the pressure trace maps of a target and an original seal impression are compared to determine whether the target seal is transcribed. Figure 7 describes the concept of the proposed detection method of a forged seal impression transcribed from the original. A 2-D image and a 3-D pressure trace map are computed for the original and suspect seal impressions. The proposed method checks whether the pressure trace pattern matches the inked region of the seal impression. Transcribed seal impressions tend to show different pressure patterns from the original. If a seal impression is authentic and not transcribed, the seal impression image and pressure trace map should match. We binarize a seal impression image to segment the inked region out of an imprinted seal. The pressure trace image obtained from a 3-D scanner is highly noisy as observed in Fig. 6*b*. To clean up the noise from the noisy pressure map with the seal pressure trace pattern unaffected, we utilize the noise distribution measured from the neighborhood of the seal impression region. We segment the inked region out of the background by thresholding. The segmented and binarized ink region is then dilated by a predefined number of pixels using morphological image operators to extract the neighborhood. Figure 8*a* shows the segmented inked region of a seal impression (Region A), and Fig. 8*b* shows the neighborhood region dilated by 30 pixels with the inked region subtracted (Region B). Regions A and B are mutually disjoint. For authentic seal impressions, Region B should not contain pressure traces.

The noise observed in the 3-D scanned seal impression may obscure the pressure pattern. To enhance the pressure trace pattern, we remove the noise in Region A using the noise

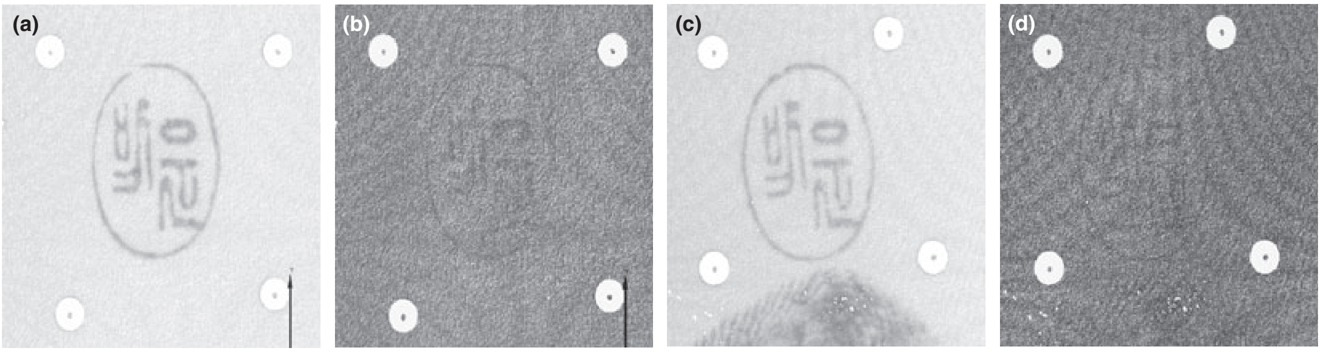

FIG. 5—*Three-dimensional scanning to measure pressure traces of a seal impression: (a) an imprinted seal in 2009, (b) pressure trace map of (a), (c) the same seal imprinted in 1994, and (d) pressure trace map of (c).*

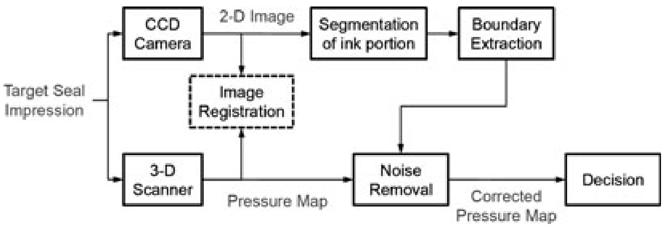

FIG. 6—*The 2-D image (a) and 3-D pressure trace map (b) of a genuine seal impression are spatially aligned with each other to have the same scale and orientation.*

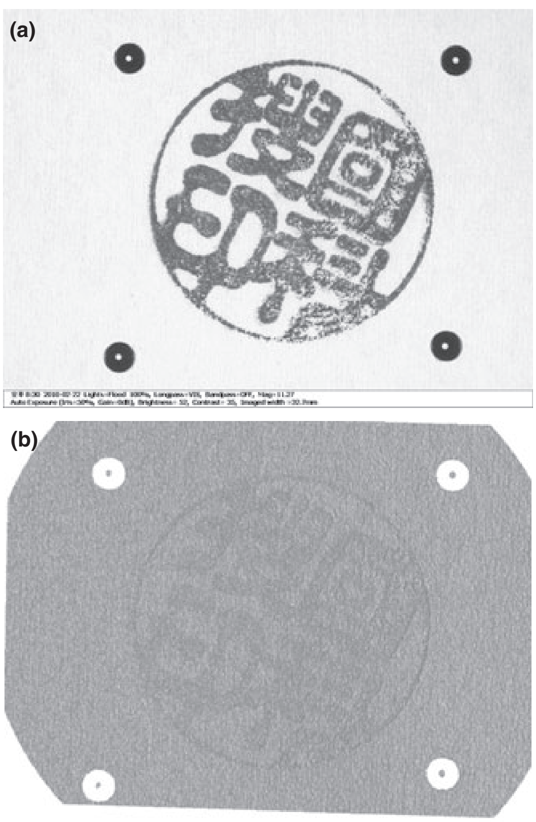

FIG. 7—*The proposed process of detecting transcribed seal impressions.*

distribution observed in Region B. We compute the mean and the standard deviation of the pixels in Region B. Then, we find the mean and standard deviation (σ) of the pixel in a 9 × 9 win-

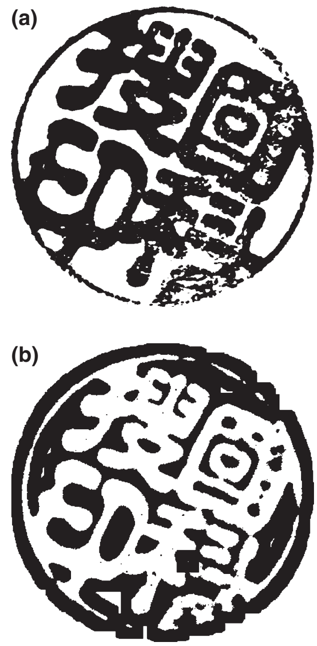

FIG. 8—*Inked region of a seal impression and its neighborhood: (a) inked region of a seal impression image (Region A), and (b) the neighborhood region dilated by 30 pixels with the inked region subtracted (Region B).*

dow centered at a pixel in Region A. If its variance is less than 1.2σ, we decide the pixel as the noise and therefore remove it. Figure 9*a* shows a pressure pattern of an authentic seal impression, and Fig. 9*b* shows corrected pressure trace map after the noise removal. Figure 9*c*,*d* are pressure trace patterns from a transcribed seal impression before and after the noise removal, respectively. Transcribed seal impressions show weak pressure trace patterns compared with the authentic seals.

We detect a transcribed seal impression using corrected pressure maps. Let $n(A)$ and $n(A_1)$ be the numbers of "1" pixels in Region A of the 2-D seal impression image and the corresponding pressure trace map, respectively. We define the pressure ratio R_A as the ratio of the pixel counts of the sets A and A_1:

$$R_A = \frac{n(A_1)}{n(A)} \quad (2)$$

Let $n(B)$ and $n(B_1)$ be the numbers of "1" pixels in Region B of a 2-D seal impression image and the corresponding pressure

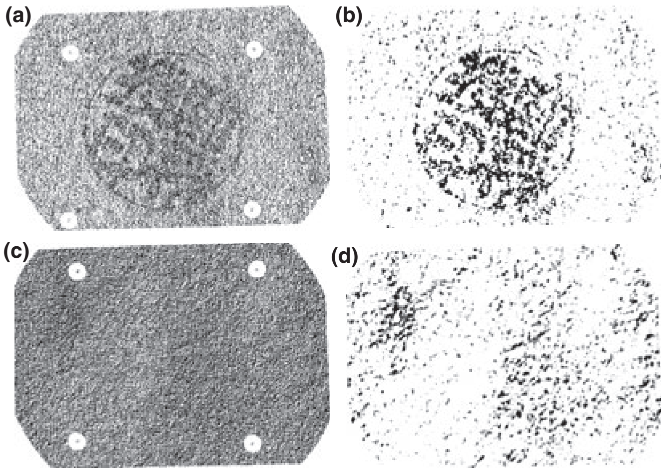

FIG. 9—*Noise removal from pressure trace images; (a) pressure map of an original seal impression, (b) pressure map of (a) after the noise removal, (c) pressure map of a transcribed seal impression, (d) pressure map of (c) after the noise removal.*

trace map, respectively. We define the noise ratio R_B as the ratio of pixel counts of the sets B and B_1:

$$R_B = \frac{n(B_1)}{n(B)} \tag{3}$$

The noise ratio represents the amount of noise level in the dilated region of the seal. The noise ratio is zero if there is no error, and it increases if the noise in the pressure map increases. Moreover, how much the image is filled inside against the area created by the outer boundary of the ink portion can be defined in terms of the noise rate. This noise gives significant effects on the degree of matching of the pressed part of a 3-D pressure map and a 2-D image of seal impression. The corrected pressure rate, which expresses how much the difference is between the image separated from the inked region and the image separated from the pressure trace, can reflect the noise rate and can be corrected as:

$$R = R_A(1 - R_B) \tag{4}$$

We can estimate the intensity of the pressure trace from the ink-smeared portion. If a document with an original impression is available, we can generate a pressure map of the seal impression. We use a maximum *a posteriori* probability estimator to check whether the corrected pressure ratio R of the target is sufficiently close to that of the reference seal impression. According to the Kolmogorov–Smirnov test (20) at a 99% error rate, the pressure ratio shows a normal distribution. In this approach, a forensic scientist can detect a forged seal impression by comparing the pressure ratio of the target seal impression with the mean and standard deviation of the pressure ratio of the original seal impression. The decision criterion can be set to 95% or 99% of the standard deviation according to the trade-off between the detection accuracy and the rejection rate.

Results and Discussion

To evaluate the performance of the proposed transcribed seal detection technique, we prepared three types of original seal impressions and two types of transcribed seal impressions. The original seal impressions were created on a regular copier paper placed on a soft pad and on a hard pad. The third original seal was the one whose seal-imprinted portion rubbed hard in an attempt to erase the sealing pressure traces. The two forgery seal impressions were transcribed, and their sealing pressure traces were created by pressing a wrong seal without ink on a transcribed seal impression. Twenty sample images are obtained for each of the five classes of seal impression types. Figure 10 shows the distribution of the original and transcribed seal patterns. Figure 11*a* shows the pressure rate distribution of the original and transcribed seal impressions in two classes. The distributions are Gaussian with the mean and the variance obtained from the data. The total error probability is 0.5654, and therefore, it has *c.* 28% of misclassification. Figure 11*b* shows the distribution of the corrected pressure rate given in Matsukawa (2). The total error probability is reduced to 0.0155, and the misclassification rate is approximately 0.77%. A bigger separation margin is shown between the two classes and therefore greater amount of generalization. We used MATLAB 2009 software (MathWorks, Natick, MA) along with the image-processing toolbox and statistics toolbox to process the data. Parts of the code were written in VISUAL C++ 6.0 (Microsoft, Redmond, WA) to speed up point processing.

Conclusions

This paper presents a detection technique of transcribed seal impressions that determines whether the sealing pressure map matches the inked pattern of a seal impression. We obtain the pressure traces of a seal impression using a 3-D scanner, and the

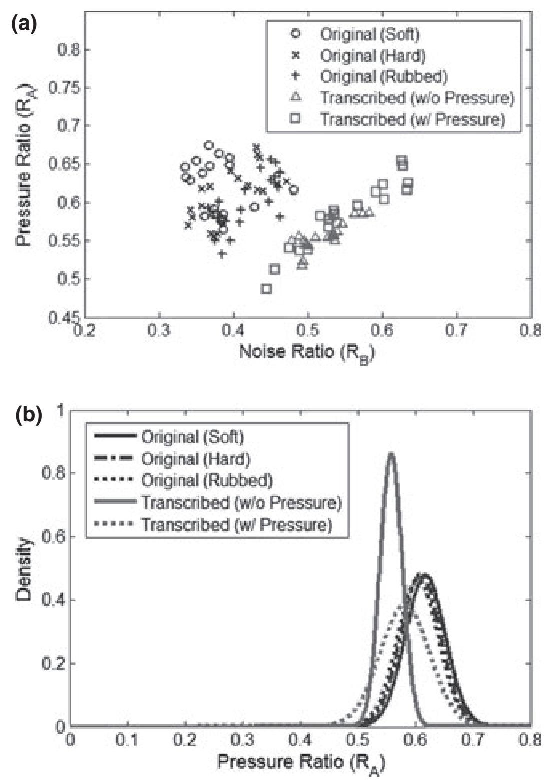

FIG. 10—*Detection of transcribed seal impressions based on the pressure map: (a) a scatterplot of the pressure and noise ratios, and (b) distribution of the pressure and noise ratios.*

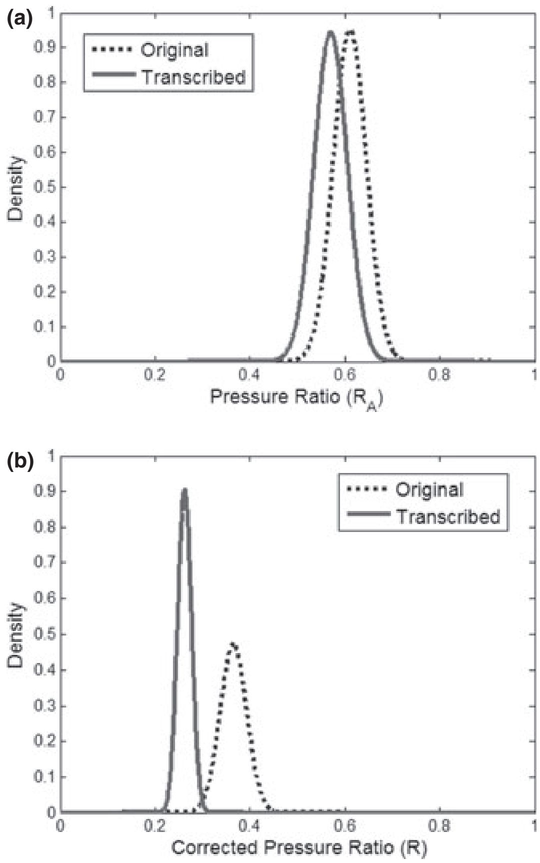

FIG. 11—*Probability distribution of the original and transcribed seal impressions: (a) the pressure ratio, and (b) corrected pressure ratio after the noise removal process.*

pressure traces are compared with the 2-D seal impression images to detect transcribed seal impressions. The proposed method offers an effective way of detecting transcribed seal impressions using 3-D pressure scanning at an error rate of 0.77%. This paper proposes a quantitative measure of the pressure trace of a seal impression and a statistical approach to detect transcribed seal impression based on the pressure ratio. The proposed method offers advantages over existing methods with a fast, nondestructive technique to detect forged seal impressions by transcription.

The proposed method assumes that a document bearing a suspect forged seal has a reasonably smooth surface. Wrinkles can affect 3-D pressure trace measurement to some degree and therefore may limit successful application of this technique. However, most important documents are unlikely to contain a large amount of wrinkles because they are well preserved. Also, artificial marks such as folds through the seal area can be removed by applying image enhancement techniques. High or low humidity levels should not affect the results. Experiment results demonstrate that the sealing pressure trace can be manifested even after a few years. The traces are still measureable even when applying pressure on the impression to destroy the pattern. Rubbing the face and the reverse side of the document cannot completely remove the pressure trace pattern that was permanently engraved in the microstructure of the paper.

References

1. National Forensic Services of Korea. The laboratory information management system database. Seoul, Korea: National Forensic Services of Korea, 2010.
2. Matsukawa T. Document validation Q&A. (ISBN: 9789574177011). Monoteru: Tokyo, 1975;211–3.
3. Yoshida K. Practical affairs on handwriting and seal inspection. (ISBN: 4-8090-1080-5). Tokyo Ordinance Publisher: Tokyo, 2004.
4. Kim DW, Yang HY, Choi S, Jin MS, Lee YS, Kim EC, et al. A study on the identification of a forgery seal impression. Seoul, South Korea: National Institute of Scientific Investigation—Annual Report 1999;31:257–64.
5. Spagnolo GS. Potentiality of 3D laser profilometry to determine the sequence of homogenous crossing lines on questioned documents. Forensic Sci Int 2006;164:102–9.
6. Kasas S, Khanmy-Vital A, Dietler G. Examination of line crossings by atomic force microscopy. Forensic Sci Int 2001;119(5):290–8.
7. Thali MJ, Braun M, Markwalder TH, Brueschweiler W, Zollinger U, Malik NJ, et al. Bite mark documentation and analysis: the forensic 3D/CAD supported photogrammetry approach. Forensic Sci Int 2003;135(2):115–21.
8. Lee J, Lee ED. A photogrammetric-analysis study of orthopedic injuries using the 3-D/CAD program. Korean J Forensic Med 2004;28(2):32–7.
9. Yang GM, Jeong NE. A preparatory study on the utilization of appraisal techniques for evaluating the causes of skin damage. Korean J Forensic Med 2008;32(2):105–14.
10. NHK Broadcasting Technology Research Center. Fundamentals of 3D images. (ISBN: 4-2740-3456-9). Tokyo, Japan: NHK Broadcasting Technology Research Center, 1995.
11. Jin H, Yezzi AJ, Tsai YH, Cheng LT, Soatto S. Estimation of 3D surface shape and smooth radiance from 2D images: a level set approach. J Sci Comput 2003;19(1–3):267–92.
12. Cochran SD, Medioni G. 3-D surface description from binocular stereo. IEEE Trans Pattern Anal Mach Intell 1992;14(10):981–94.
13. Quan C, He XY, Wang CF, Tay CJ, Shang HM. Shape measurement of small objects using LCD fringe projection with phase shifting. Opt Commun 2001;189(1–3):21–9.
14. Barnard ST, Thompson WB. Disparity analysis of images. IEEE Trans Pattern Anal Mach Intell 1980;2(4):333–40.
15. Reich C, Ritter R, Thesing J. 3-D shape measurement of complex objects by combining photogrammetry and fringe projection. Opt Eng 2000;39(1):224–31.
16. Yoshida K. From basics to practice of document appraisal. (ISBN: 4-8037-0429-5). Tachibana Shobo: Kyoto, 1983;119–26.
17. Yamamoto T, Yoshimura T. Seal comparison test of the superimpose. Jpn J Sci Technol Identification 2008;Vol. 1(Suppl. 13):193.
18. Otsu N. A threshold selection method from gray-level histograms. IEEE Trans Syst Man Cybern 1979;9(1):62–6.
19. Trier OD, Taxt T. Evaluation of binarization methods for document images. IEEE Trans Pattern Anal Mach Intell 1995;17(3):312–5.
20. Fasano G, Franceschini A. A multidimensional version of the Kolmogorov–Smirnov test. Monthly Notices of the Royal Astronomical Society 1987;225:155–70.

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