



Sequence discrimination of heterogeneous crossing of seal impression and ink-printed text using adhesive tapes



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ABSTRACT

This paper presents a technique to discriminate the sequence of stamped seal impression and ink-printed text in a document to detect falsely signed documents. In many Asian countries where a seal is widely used to endorse documents, a possibly forged document involves a seal impressed before the text is printed. The proposed method uses adhesive tapes with peel adhesion strength of approximately 25 oz/in. to exfoliate the top layer of the overlapping region of seal impression and ink-printed text in the document. A pair of digital images of the overlapping region, captured using an infinite focus microscope, is compared for color changes before and after the exfoliation with adhesive tapes. The proposed sequence discrimination index (SDI) measures the amount of color changes before and after the exfoliation to determine the sequence of seal impression and printed text. Experiment results show that the SDI successfully discriminates the sequence of seal impression and printed text for different types of ink cartridges and seal inkpads under various storage conditions, enabling forensic investigation of falsely signed documents with a seal.

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1. Introduction

There have been a growing number of criminal cases related to document forgery and alteration with sophisticated skills [1]. In many Asian countries such as Korea, Japan, and China, seals have been widely used over signatures to endorse a document to confirm the person's agreement, verification, responsibility, and guarantee. In most circumstances, stamped seal impressions and printed text are in different colors, often using red-colored inkpad for seal impressions and black ink for printed text. Seal inkpads consist of the components such as lubricating oil, fillers, and pigments. A person makes a seal impression on a printed document after the person reads and agrees on the content of the document. Therefore, a seal impression will appear over the printed text of the document. In case a seal is impressed on a blank document before the text is printed, then the printed text will appear over the printed text, and the document is likely to be falsified. Therefore the discrimination of the sequence of seal impression and printed text is crucial to determine whether a document endorsed with a seal is authentic or forged.

Several attempts have been made to discriminate the sequence of seal impression and printed text in a document. Examination

methods involving chemical treatments tend to damage the document permanently. Some methods lack objectivity, therefore the discrimination results may not be accepted as evidence. One of the popular conventional methods is that an examiner magnifies the overlapping region of seal impression and printed text in the document with an aid of an optical microscope to visually discriminate whether the seal is impressed over or under the printed text [2]. This approach is rather subjective and depends highly on skill levels and experiences of the examiner. Since the seal impression layer is as thin as 20–50 nm, visually discriminating the sequence of printed text and seal impression can be a challenging task. To improve the visual inspection method with an optical microscope, Yoshida et al. [3] used a red filter together with a microscope, observed the discontinuity of printed text to determine the sequence. However, if the discontinuity area is not wide enough, this method may not be effective. Lee et al. [4] used time-of-flight secondary ion mass spectrometry (ToF-SIMS) to analyze chemical components of a seal inkpad, and discriminated the sequence of seal impression and ink-printed text in the document. This method works only when the weights of calcium (Ca) and lead (Pb) exceed a certain level and requires many samples for pre-treatment for the analysis. This method also requires the analysis of the components of the paper before analyzing the samples to distinguish seal inkpad components from the paper. Sequence discrimination approaches using an infrared spectrometer [5,6] and Raman spectrometer [7] have been also

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proposed. Such methods can be impractical in actual document examination due to the requirement of pre-treatment, limited sensitivity of the equipment, possible damage to the sample, and the problems concerning the distinction from paper components. In case only a small number of samples are available for sequence discrimination, we used an atomic force microscope (AFM) to discriminate the sequence of seal impression and printed text. The AFM cantilever exfoliates the top layer of an overlapping area of toner-printed text and seal impression to uncover the material under the top layer to discriminate the sequence. However, the AFM method was not effective for ink-printed documents since ink-printed text layer is thinner than the toner layer, making it difficult for AFM cantilever to remove the top layer effectively even using the minimum force possible of the cantilever.

This paper presents a sequence discrimination method of stamped seal impression and ink-printed text in a document using off-the-shelf adhesive tapes to remove the top layer of the overlapping region of seal impression and printed text. The proposed discrimination technique is effective in case of a heterogeneous crossing of seal impression and ink-printed text of different color and ingredients that do not mix up. Transparent adhesive tapes have versatile uses in forensic investigations to collect minute evidences from a crime scene not so visible to naked eyes [8]. Transparent tapes enable visual observation of the collected substances through the opposite side of the adhesive surface [9]. Adhesive tapes are also used to manufacture graphene in the mechanical exfoliation method, where adhesive tapes remove a layer of carbon from a graphite flake [10,11]. Since adhesive tapes are often made of sticky materials on an unabsorbent substance, the tapes have been used to reproduce fraudulent seal impressions that were copied from authentic seal impressions stamped in an original document [8]. Seal inkpad consists of oil-based hydrophobic components while printing ink contains water-based hydrophilic components creating a stronger horizontal bondage and a weaker bondage in a vertical direction. This lowers inter-layer friction factors, enabling an effective separation of the top layer from the bottom layer using adhesive tapes [12].

2. Sequence discrimination of seal impression and printed text with adhesive tapes

The proposed sequence discrimination technique uses adhesive tapes as a tool to exfoliate the top layer in the overlapping region of seal impression and ink-printed text. We capture a pair of color images of the same overlapping region before and after removing the top layer using adhesive tapes. We spatially align the two images using an affine transformation to find spatial correspondences for

comparison. Then we quantify the changes in color of the overlapping region before and after removing the top layer using the proposed sequence discrimination index (SDI) for sequence discrimination of seal impression and printed text. The sequence discrimination task is conducted in the following three processing steps: (1) image registration, (2) segmentation of pixels into seal impression and printed text classes, and (3) computation of SDI of the overlapping region. If the SDI of an overlapping region exceeds a certain threshold, we determine that the seal is impressed over the text and therefore the document is authentic. On the other hand, if the SDI is below the threshold, then the document is determined possibly forged.

2.1. Image registration

We acquire a digital image of a target overlapping region of seal impression and printed text in a document using an infinite focus microscope (Alicona, G4). Another image of the same overlapping region is captured after removing the top layer using an adhesive tape. Since the two images do not match exactly, we spatially align the images for comparison. To find spatial correspondences between the two images, we extract a set of prominent feature points from an image and the corresponding features from the other image. Among many feature extraction algorithms [13–15] that find feature points invariant to scale and illumination, the scale-invariant feature transform (SIFT) algorithm [16] and the speeded-up robust features (SURF) algorithm [17] have been widely used. Since the SURF algorithm demonstrated higher processing speeds than the SIFT, the SURF algorithm was used to extract feature points for aligning the image pair of the overlapping region. Some outlier features having a large deviation from the rest of the data are excluded using the RANSAC (Random Sample Consensus) algorithm [18] for optimal image registration results.

After finding two sets of corresponding feature points from the image pair, a geometric transformation is applied to spatially align the two images. A geometrical relationship of an image pair is determined by scale (image size), rotation angle, and translation. An affine transformation transforms the target image to align it to the reference image

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

where (x, y) and (x', y') represent the coordinates of a pixel before and after the geometric transformation, parameters s and θ denote the scale and the rotation angle, t_x and t_y are the translation parameters. Fig. 1 shows registered images of an overlapping region of seal impression and ink-printed text in a document,

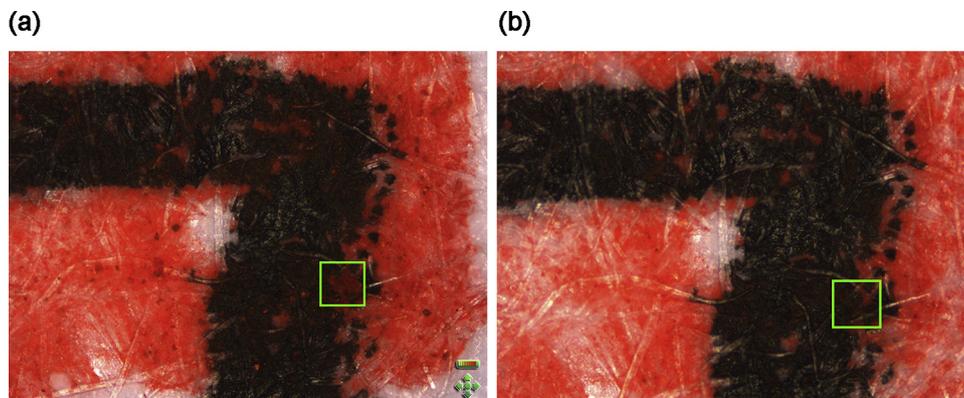


Fig. 1. Spatial alignment of an image pair of an overlapping region of seal impression and printed text captured before and after removing the top layer using an adhesive tape; (a) before exfoliation, (b) spatially aligned image pair using the affine transformation.

where a seal is impressed over printed text. The overlapping region of physical size of approximately $2.5 \text{ mm} \times 3 \text{ mm}$ is magnified by 30 times and digitized into a digital image of 1081×821 in pixels. Fig. 1(a) is an image of the overlapping region before exfoliation while Fig. 1(b) shows the image registration result of the two images before and after exfoliation using the affine transformation. Initially 100 pairs of corresponding feature points were extracted using the SURF algorithm. After removing nine pairs of feature points with large deviations using the RANSAC algorithm, 91 pairs of feature points were actually used to align the two images. The calculated parameter values in the transformation were $s \cos \theta = 0.9297$, $s \sin \theta = 0.0035$, $t_x = 9.8612$, and $t_y = -16.5510$. In the examination window, a small rectangle in the image of size 104×102 , the exfoliation using adhesive tapes removed a portion of seal stamp in the top layer.

2.2. Segmentation of pixels into seal impression and printed text classes

The next step is to segment out the pixels corresponding to seal impression and printed text from the background. We binarize the registered images of the overlapping region to segment the pixels into two classes, seal impression and printed text. To segment out the pixels of the seal impression region from the background, we apply the Otsu's binarization algorithm [19] to the histogram of color difference between red and green (R-G). A histogram of the color difference R-G is effective to segment seal impression from the background since red-colored seal impression pixels have a very low value in green color component compared to the background pixels. To segment out the pixels of the printed text, we applied the Otsu's algorithm to a black-and-white histogram of the images before and after exfoliation. Fig. 2(a) and (b) shows image segmentation results of seal impression (Red) and printed text (Black) in the overlapping region from the background (White) of the sample in Fig. 1(a) and (b), respectively. The number of pixels of printed text (black) inside the examination window increased after peeling off the top layer of seal impression (red) using adhesive tape.

2.3. Sequence discrimination index

Removing the top layer of the overlapping region makes affects color distribution of the image pixels. Therefore, the change in color component histograms plays a key role to discriminate the sequence of seal impression and printed text. We propose the sequence discrimination index as a metric to quantify the amount of changes in red color histograms. SDI is defined as the ratio of the number of pixels $N(\Delta B)$ turning from red to black and the number

of pixels $N(\Delta R)$ turning from black to red in the examination window of the overlapping region.

$$SDI = \frac{N(\Delta B)}{N(\Delta R)} \quad (2)$$

If a seal is impressed over ink-printed text, the seal inkpad portion will be exfoliated by the adhesive tape. Thus, red color components of seal impression will decrease and a portion of printed text color under the seal impression will be revealed, which will increase the number of black pixels. If the text is printed over seal impression, on the other hand, the adhesive tape peels off ink-printed text portion. And black color components of printed text will decrease and a portion of seal impression comes to the front, which will increase the number of red pixels. We determine whether a document endorsed by a seal is authentic or forged based on the SDI value with a threshold.

$$\text{decision} = \begin{cases} \text{document authentic} & \text{if } SDI \geq \theta \\ \text{document forged} & \text{if } SDI < \theta \end{cases} \quad (3)$$

Fig. 3 shows the effect of exfoliation using adhesive tapes for a forged document, where the text is printed over seal impression. The number of pixels of printed text (black) in the examination window of size 159×114 pixels in Fig. 3(a) decreased as in Fig. 3(b) as a result of exfoliation using adhesive tapes. In this case, the SDI was 0.0446 since $N(\Delta B) = 2664$ and $N(\Delta R) = 59,687$. For an authentic seal impression in Fig. 1, the SDI was 0.868 since $N(\Delta B) = 8120$, $N(\Delta R) = 9349$.

3. Experiment results

3.1. Preliminary test

A preliminary test was performed to check if various types of adhesive tapes can effectively remove the top layer of the overlapping region of seal impression and printed text without damaging the sample surface. Eight commercial adhesive tape products were tested for the suitability in sequence discrimination. Adhesive tapes were grouped into four categories according to their peel adhesion strength: weak, average, strong, and very strong. Table 1 summarizes peel adhesion strength of adhesive tapes and their characteristics in the sequence discrimination. Adhesive tapes with strong and very strong peel adhesion strength of 30 oz/in. or higher damaged the target document. Weak adhesive tapes with peel adhesion strength of 13 oz/in. or below failed to provide sufficient adhesive strength to remove the top layer of ink-printed text. Transparent adhesive tapes with

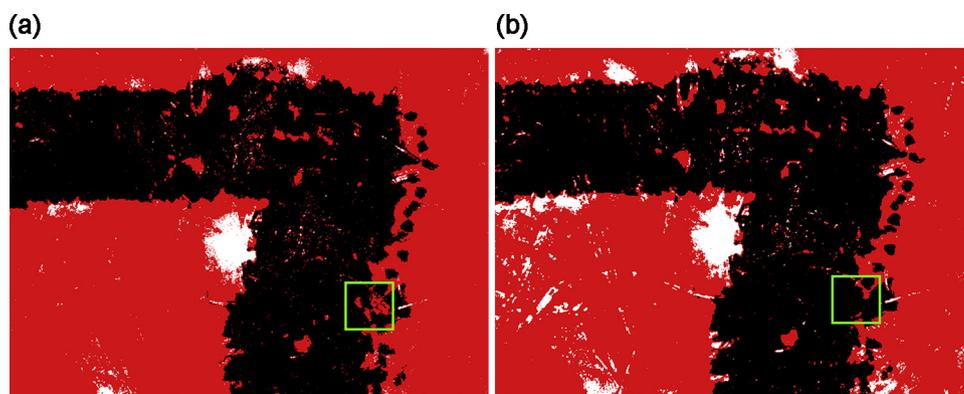


Fig. 2. Segmentation of image pixels into seal impression (Red) and printed text (Black) classes from the background (White) using the Otsu's algorithm; (a) segmentation result of Fig 1(a) and (b) segmentation result of Fig. 1(b). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

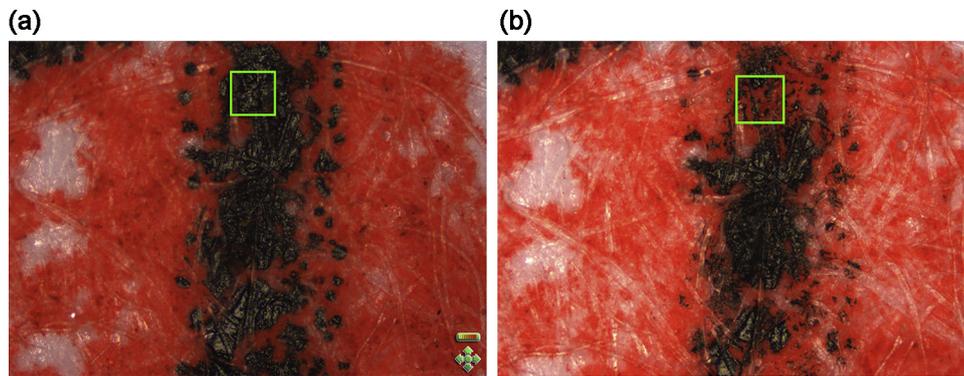


Fig. 3. Color changes of a forged document with printed text over seal impressions; (a) before exfoliation with adhesive tapes, (b) after exfoliation.

adhesion strength of 25 oz/in. proved most appropriate for sequence discrimination.

3.2. Sequence discrimination test

To confirm the performance of the proposed sequence discrimination method of seal impression and ink-printed text, we prepared 26 document samples, 13 samples of authentic documents where seal is impressed over printed text and 13 samples of forged documents where the text is printed over seal impression. Document samples were prepared using various popular inkjet printer cartridges and commercial inkpad products printed on a general-purpose white copier paper (75 g/m²). Four types of inkjet printers were used: Canon Pixma MX366, HP Officejet G95, Epson Stylus TX228, and Samsung SCX 1455i. Red inkpads used for seal impression consist of ingredients such as lubricating oil, fillers, and pigments. For the 13 forged document samples of printing-after-stamping, we printed the text over seal impression after 24 h of stamping a seal to ensure the seal impression becomes sufficiently dry. For the other 13 authentic document samples of stamping-after-printing, a seal was impressed 3 h after printing the documents with an inkjet printer. To simulate the testing conditions to the case of actual examination scenarios, both types of samples were kept for two days in a room condition of temperature of 25 °C and humidity of 30–35% before testing. For the removal of the top layer of the overlapping region, we applied adhesive tape on the examination area of the sample placed on a flat table and pressed 2–3 times with an appropriate amount of force. The crossing area of seal impression and printed text, before and after exfoliation using adhesive tape, was imaged using an infinite focus microscope.

Fig. 4 shows the changes in red color histograms in the examination windows of the overlapping region of seal impression and printed text before and after exfoliation using adhesive tapes. Fig. 4(a) shows the red color component histograms for an authentic document in Fig. 1. Since seal is impressed after text is printed in the document, a portion of seal inkpad was removed due

to the exfoliation using adhesive tapes, uncovering more black pixels. The red color component histogram shows a significant amount of shift to left after removing the top layer of the overlapping region since ΔR decreases and ΔB increases. On the other hand, green and blue color component histograms do not show much change before and after the exfoliation. Fig. 4(b) shows red color component histograms for a forged document, where printed text appears over seal impression. The exfoliation removes ink-printed text portion in the top layer. Therefore, ΔR increases and ΔB decreases, causing red color component histogram shifts right due to an increase in red pixels of seal impression. Fig. 5 shows the sequence discrimination test results for the 32 document samples. The proposed method successfully discriminated the sequence of seal impression and ink-printed text for all the document samples.

To check if the proposed sequence discrimination method can be effective for various types of inkjet printer and seal inkpad, we prepared twelve document samples, 6 authentic and 6 forged ones, using three types of inkjet printers and two types of inkpads. Document samples in experiments 1 and 2 were prepared using CANON Pixma MX366, HP Officejet G95 for experiments 3 and 4, and EPSON Stylus TX228 for experiments 5 and 6. In Fig. 6, the proposed method successfully discriminated the sequence of seal impression and printed text for all 12 document samples regardless of printer ink and inkpads. To confirm the effectiveness of the proposed sequence discrimination method under various document storage conditions, the document samples were kept for two days in the temperature conditions of 0 °C, 25 °C, and 70 °C and in the humidity conditions of 4%, 21%, and 80%. Tests revealed that the proposed sequence discrimination method was equally effective under various temperature and humidity conditions.

Tests were conducted to check if the testing can be influenced by time duration of adhesive tape application or document storage. We applied adhesive tapes to ten document samples with the same amount of force of 250 g for 5 s, 30 s, 1 min, 5 min, and 10 min. Fig. 7(a) shows that the discrimination results were not influenced

Table 1

Categorization of adhesive tapes in terms of peel adhesion strength and their characteristics in sequence discrimination.

Peel adhesion strength (oz/in.)	Number of product tested	Observation
Very strong (45–60)	3	Damaged document surface Unable to discriminate the sequence
Strong (30–40)	3	Damaged document surface Sequence discrimination somewhat possible
Average (25)	1	Did not damage document surface Most appropriate for sequence discrimination
Weak (13)	1	Did not damage document surface Does not exfoliate the top layer of the overlapping region

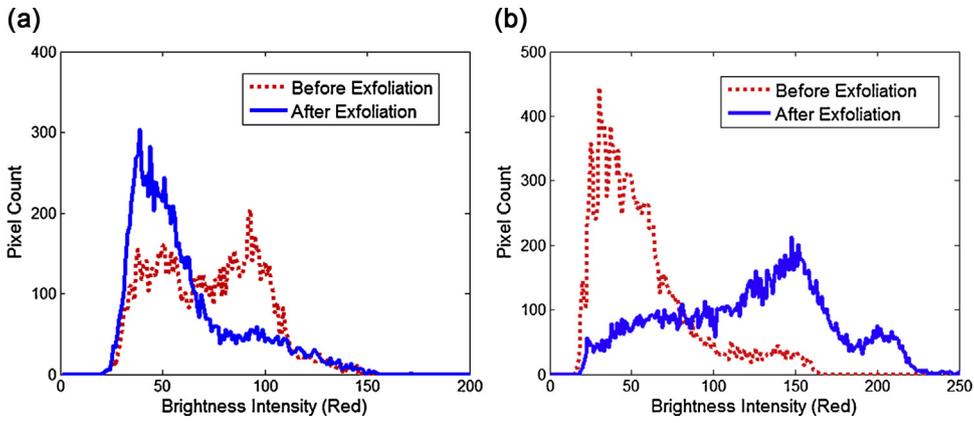


Fig. 4. Red color component histograms before and after exfoliation using adhesive tapes; (a) authentic document (seal impression over printed text), (b) forged document (printed text over seal impression). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

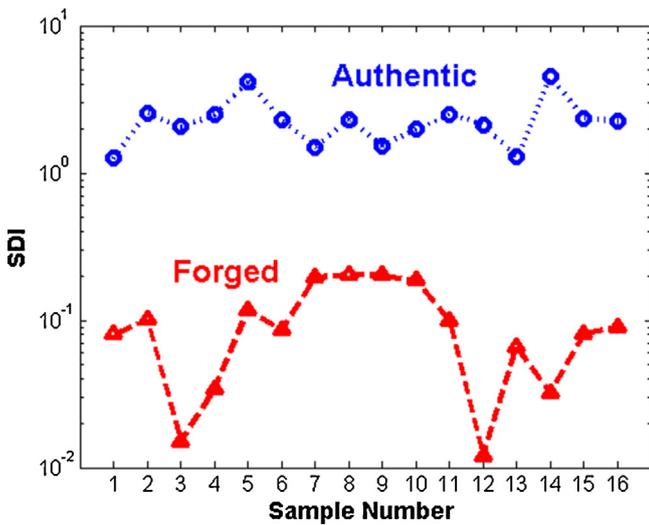


Fig. 5. Sequence discrimination results for the 16 forged and 16 authentic document samples.

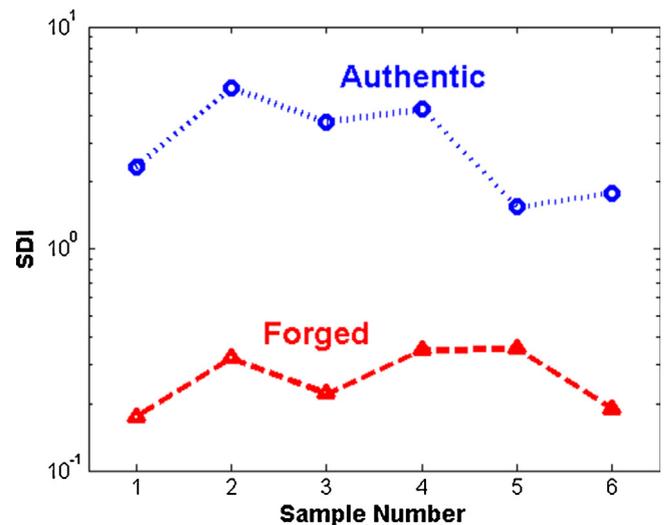


Fig. 6. Sequence discrimination of seal impression and ink-printed text for various printers.

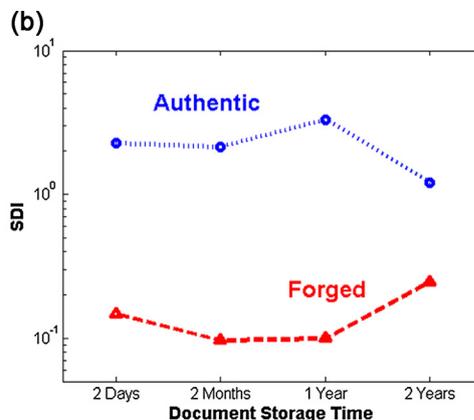
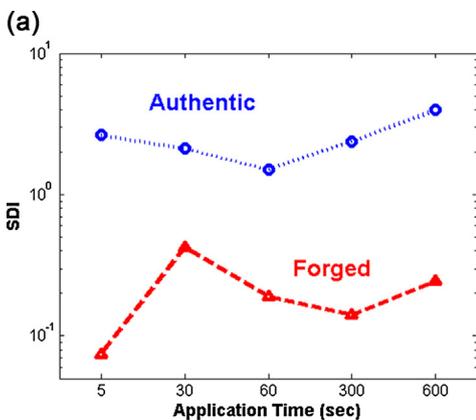


Fig. 7. Sequence discrimination results for the samples with adhesive tape application time duration and document storage time; (a) time duration of adhesive tapes, (b) document storage time.

by the time duration of adhesive tape application. Fig. 7(b) shows that the sequence discrimination method using adhesive tapes worked equally well for the document samples stored for 2 days, 2 months, 1 year, and 2 years.

We confirmed the same trend from a double blind test performed on 50 samples of authentic documents with the seal

imprinted on ink-printed text and 50 samples of forged documents with the text printed over seal impression. The highest SDI value of forged documents was 0.0078 and the smallest SDI value of authentic documents was 2.1110, revealing a sufficiently large separating margin that separates the two classes for all 100 samples used in the test.

4. Conclusion

This paper addresses sequence discrimination of stamped seal impression and ink-printed text in a document for the investigation of falsely signed documents. Using general-purpose transparent adhesive tapes with peel adhesion strength of approximately 25 oz/in., we removed the top layer of the overlapping region of seal impression and printed text to reveal the materials under the top layer. A pair of digital images, taken from before and after exfoliation, are spatially aligned and examined for color change in the overlapping region. After finding the number of pixels turning from red to black and the number of pixels turning from black to red before and after the exfoliation using adhesive tapes, we compute the sequence discrimination index, a proposed metric to quantify the amount of changes in color components before and after the exfoliation. For a forged document involving printed text over seal impression, the exfoliation using adhesive tapes will remove a portion of printed ink text in the top layer of the overlapping region, resulting in a decrease in the black component and an increase in the red component. For an authentic document where seal is impressed over printed text, the exfoliation removes seal inkpad in the top layer, reducing red color pixels. Then we compute the sequence discrimination index SDI as the ratio of the number of pixels turning from red to black (ΔB) and from black to red (ΔR). The red color component histograms involves a significant amount of shift as a result of exfoliation and the direction of histogram shift reveals if the document is authentic or forged. The proposed technique successfully discriminated the sequence of seal impression and printed text for a number of document samples prepared using various types of inkjet printers, seal inkpads, and in various document storage conditions as well as time duration of adhesive tape application. Experiment results show that the proposed method can be applied to forensic investigation for falsely signed documents by discriminating the sequence of seal impression and printed text in the documents.

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