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A Study on the Objective Identification of Inkjet- and Toner-printed Characters Using the Adhesive-Tape Exfoliation Method

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Abstract

With the advancement in the development of office automation equipment, it is trendy to produce important documents using printing methods rather than writing them. Thus, identifying the type of printing method used is the most essential and important part of the research on document forgery, which is largely focused on the identification of forged documents. In particular, the printing method identification technique should be able to analyze the shapes of the printed characters and obtain diverse information to be able to specify the type of printing device that was used to print the document. Thus, the identification of the printing method that was used can resolve forgery problems by itself, and as such, diverse studies are currently being conducted to enable the identification of the type of printed characters in relation to the type of printer used. In particular, if such identification method can minimize the damage to the appraisal target, and if the results can be quantified and objectively derived, it will be highly useful in forensic science, where the objectification of judgment is important.

In this study, a method of identifying the printing method that was used (inkjet vs. toner printer) for printing a document was examined by binarizing and quantifying the images of the printed characters produced from the exfoliation method using adhesive tape.

Keywords: Toner-printed Characters • Inkjet-printed Characters • Forgery of Documents • Adhesive Tape • Physical exfoliation method

Introduction

With the advanced development of office automation equipment, anyone can easily produce delicately forged documents, which can be directly or indirectly used in crimes. In forensic science, it is very important to establish criteria for judging forged documents when investigating crimes involving document forgery and when analyzing relevant evidence, and to set up techniques for acquiring the overall information of the documents involved [1-3]. In particular, to be able to judge forgery, it is most important to identify the printing method that was used to print the document based on the printed characters, as well as the type of printer that was used, and many studies on this theme are currently being conducted [4-6]. Among forged printed documents, black-and-white documents generally matter more in forensic science than colored documents. If printed documents are examined in comparison with their original documents only by enlarging and then inspecting them, it will take much time and effort to inspect all the details of the printed characters, and forged printed characters, if added to the first printing, may be easily overlooked in the examination. In addition, the samples used in forensic analysis are mostly used as evidence in legal proceedings and are highly likely to be reused later for other possible arguments; as such, the samples of the documents involved should not be damaged, or their damage should be minimized when analyzing them. Thus, studies should be conducted to come up with effective criteria for meeting all these requirements and yet allowing the identification of the type of printer that was used to print a black-and-white document.

A study already reported to the academia a way by which, using the adhesive-tape exfoliation method, etc., it can be judged, in a part of the document where the target printed characters and the seal imprint overlap, which between the printed characters and the seal imprint came first and which came later [7,8]. People generally produce a document by first printing it and then signing it or stamping their seal on it. If this sequence is reversed (i.e., if the document is printed after signing or sealing it), it is suspected of having been forged. Thus, it is important to identify which between the printed content and the signature or seal imprint came first and which came later to determine if the document was forged. If a document has a part where the printed content and the seal imprint overlap, the reported adhesive-tape exfoliation method can determine the sequence of the document printing and seal imprinting, and can indicate the possibility of forgery.

In the research that was conducted on the above theme, the importance of identifying the type of printed characters on the concerned document was recognized, and the interest in the theme was hinged on the realization that such identification is essential when examining documents for forgery, in various stages of the examination, and that this judgment may totally change the forgery examination method and order that are currently being used in forensic science [9,10].

Tapes are cheap and easy to buy, and are used for various purposes. Forensic science uses tapes to gather fine evidence that is difficult to observe visually. Adhesive tapes can gather fine substances, and transparent tapes allow one to observe all the gathered substances on the side opposite the adhesive side [11]. Tapes are used in the manufacture of graphene, which is currently on the spotlight as a new material, and the use of Scotch Tape™ can separate a layer of carbon from graphite flakes, a method called “mechanical exfoliation method” or “Scotch Tape method” [12,13]. Tapes are used in the crime of transcription of sealed imprints as being adhesive and non-absorbent; they can be used to transcribe the shape of an imprint to a different document by attaching part of the impressed stamping ink to the tape [14].

Based on the authors’ previous research as well as examples of examination in relation to tapes, the difference between the adhesive-tape exfoliation patterns of ink- and toner-printed contents was examined, and how to effectively quantify and identify the images before and after such exfoliation is discussed herein.

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Experiment

The experiment specimen, a pre-exfoliated image of the surface of the printed-characters portion of a document, was first photographed [15]. A piece of tape was then attached to the experiment specimen for the exfoliation of the printed characters, and the tape was later removed horizontally. The specimen's surface was again photographed [16]. The photographed pre-exfoliated image of the printed-characters portion was placed over the image of the tape film that was used for the exfoliation for purposes of overlapping, observing the exfoliated amount, and comparing the images. The said two images were binarized to determine the quantity of ink that was transcribed to the tape based on the pixel count of the printed characters, and to judge the printing method that was used for the document based on the quantity of ink that was transcribed to the tape.

Transparent adhesive tape should be attached to the ink-printed characters portion, after which the top layer should be removed and the characters reflected thereon should be read. The part of the document to which the tape was attached should be photographed before and after the removal of the top layer using adhesive tape, the image data should be acquired and matched, and the pixel count should be calculated to determine if there is a difference between the images taken before and after the removal of the tape.

When photograph the characters or tape film using digital camera, it is converted to pixel data, so it stored to data using CMOS or CCD image sensor with a pixel sensors with red, green and blue filter (Figure 1).

Pixel is the smallest unit of digital image and it contains numerous of pixels. The pixels are shown as 16,581,375 colors using the red, green and blue which it have depth of 255 layer. For example, RGB values of black pixel represent as "0, 0, 0" and white pixel is "255, 255, 255". For quantitative comparison and evaluation, there are too many RGB values to separate clearly.

Therefore, convert it to binary image using statistical scheme calculate total RGB values of the image. So it correctly split to black pixel(RGB value: 0,0,0) and white pixel(RGB value: 255, 255, 255).

Also, the photographed images of the experiment specimen before and after attaching adhesive tape thereto and removing the top layer may not perfectly match each other given that the tape was removed for photographing purposes and the images are different in size (scale) and rotational angle. Thus, to identify the possible difference in the experiment specimen images before and after the removal of the top layer with adhesive tape, the two images should be spatially matched with each other. To match the two images, the common features of the objects in the images should be discovered to be able to calculate such spatial changes as a parameter.

The methods of determining the corresponding points in images consist of the area- and feature-based methods. The feature-based method extracts the features of images and tries to match these. As this method requires less time, it has become more popular, and many studies on it have already been conducted and published [17-19]. Of the algorithms falling under this method, the SIFT (Scale-invariant Feature Transform) algorithm [20] and SURF (Speeded-up Robust Features) algorithm [21] are widely used. The SURF algorithm, compared to the SIFT algorithm, has significantly improved in treatment speed and is superior in discovering features invariant to the environment, such as the scale, lighting, and viewpoint of the target image. Such feature-based algorithms, however, are weak in discovering simple and repetitive patterns of images without particular features. The area-based method, on the other hand, performs matching for all the pixels, which requires more time, giving such method a disadvantage, but it simplifies the calculation and is excellent for identifying images with particular features.

As ink-printed characters have simple patterns, matching was performed in this study using the area-based method. The acquired images were quantified in the following stages:

1. Binarization
2. Matching of Images
3. Quantification of the amount of ink transcribed to the adhesive tape after adhesive-tape exfoliation

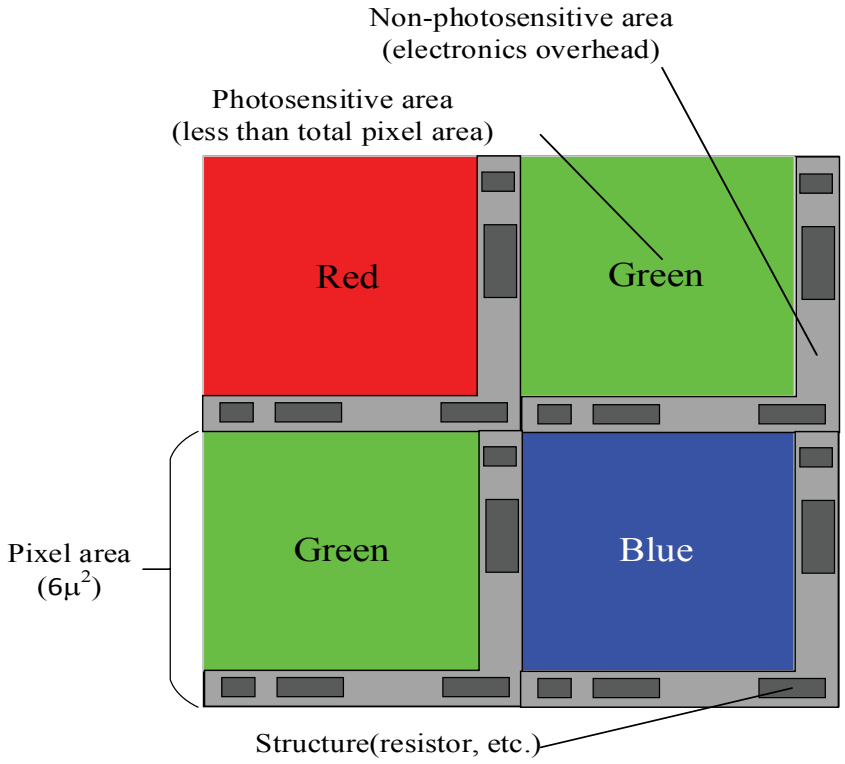

Figure 1. Pixel sensor photodiode architecture.

Results and Discussion

Binarization

For the first step, the input image into the black-character area and the white-paper background should be separated, and one of the widely used methods for this involves providing a threshold to the input image to change it to a binary image. At this time, the threshold value is set by Otsu's algorithm using the statistical method of the global histogram [22].

Figures 2 and 3 show a histogram of the input images and their brightness values (grey levels), and Figure 4 shows an image binarized from the input image using the threshold obtained by Otsu' method (the red vertical line in Figure 4).

Matching of images

To register the reference image before exfoliation and the image after exfoliation, the parameters of shift, rotation, and scale should be obtained.

$$A = \{a_{(x,y)} \mid a_{(x,y)} \in \text{Reference image before exfoliation}, a_{(x,y)} = 1\}$$

$$B = \{b_{(x,y)} \mid b_{(x,y)} \in \text{Image after exfoliation}, b_{(x,y)} = 1\}$$

The optimized registration of reference A and input B involves the process of obtaining the shift and rotation parameters that make the matching pixel count the maximum, as shown in expression (1).

$$(\nabla\theta, \nabla x, \nabla y, \nabla S) = Arg\max(MPC)$$

$$MPC = \sum T(x,y) \quad T(x,y) = \begin{cases} 1 & ,if\ a_{(x,y)} = 1,\ b_{(x,y)} = 1 \\ 0 & ,otherwise \end{cases}$$

Using the above method, the shift, rotation, and scale parameters were obtained, and the corresponding images were transformed based on the reference image, using the equation below.

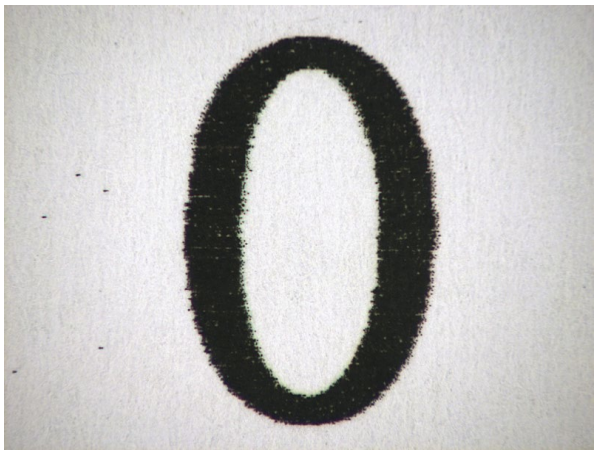

Figure 2. Input image.

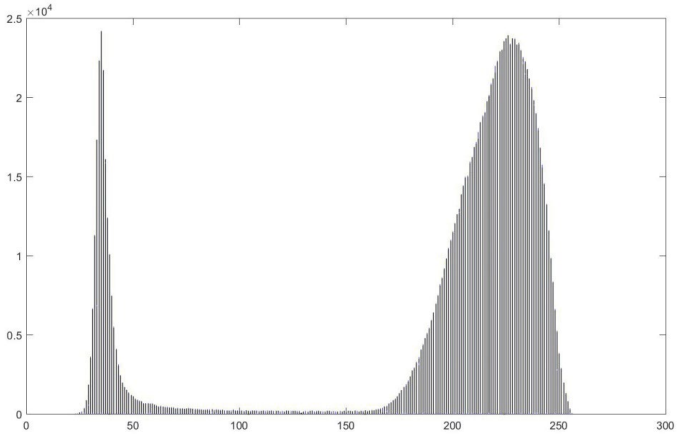

Figure 3. Histogram of input image.

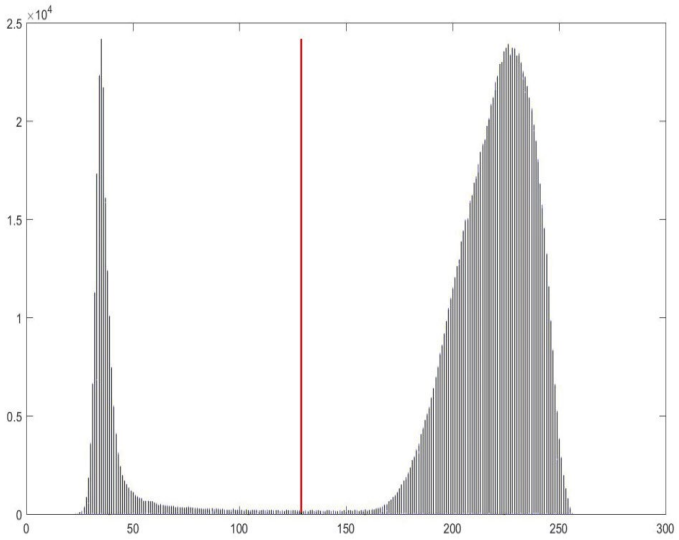

Figure 4. Histogram applied by Otsu threshold value.

If the geometric relationship between the two images is determined by the affine transformation represented by the scale, the rotation angle, and the positions in the x- and y-axis, the relationship between the pixels before and after transformation is expressed by the transformation matrix below.

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

Acquisition of the quantified value of the relationship before and after exfoliation

In the overlapping of the images before and after the exfoliation of the top layer with adhesive tape, the count N (delta W) of the pixels where black was changed to white is considered the amount of ink detached while the count N (delta B) of the pixels where white was changed to black is considered an error created in the image registration process. The relationship index (I) with the reflection of this error after the exfoliation of the printed characters is considered I = N(delta W)*(1 - N(delta B).

The observed surface alone of the printed-characters area as exfoliated with the tape seems to show a big difference between the inkjet and toner printing methods, as shown in Figure 5 and 6, but to ensure the reliability and objectivity of the proposed method, this study accurately expressed the amount of the transcribed printed characters. The method indicated a clear change in the final images of the printed characters, making comparative analysis easy, and it was shown to accurately extract and match the points, thus making it easy to effectively determine where a change occurred in the printed characters by comparing the images before and after exfoliation. In addition, based on the experiment results, the amount exfoliated and the change amount of the printed characters of the specimen, together with the images, were provided to make it possible to identify diverse printed documents.

The adhesive-tape exfoliation method for finally identifying printed characters consists of the stages below:

1. Acquiring the image of the printed characters of the specimen before exfoliation.
2. Exfoliating the surface of the printed characters using adhesive tape.
3. Acquiring the image of the printed characters after their exfoliation, and the image of the printed characters being transcribed to the adhesive tape.
4. Binarization of the image of the printed characters after their exfoliation,

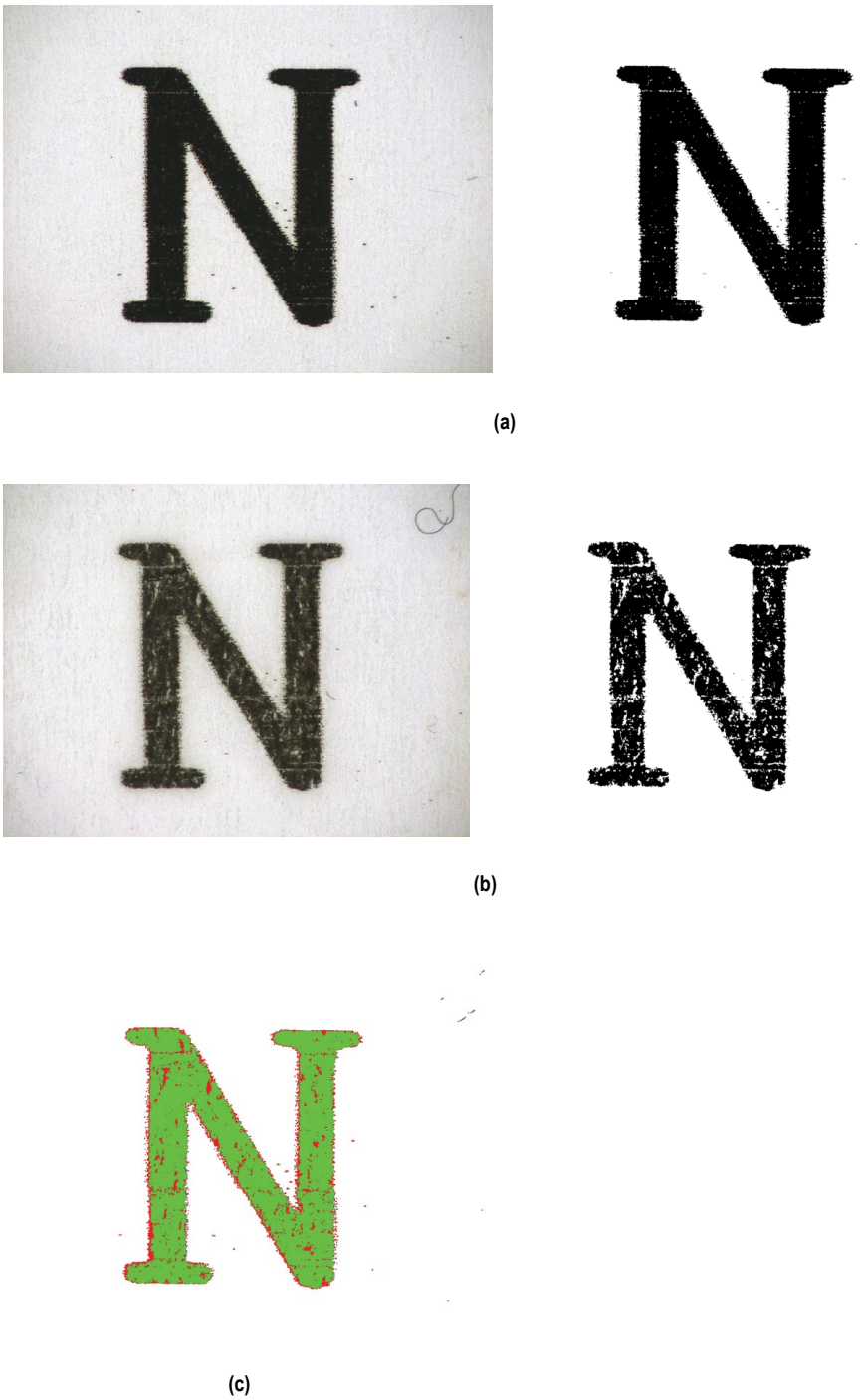

Figure 5. Binarization and quantification of the inkjet-printed characters exfoliated with adhesive tape. (a) Binarized image of the inkjet-printed characters before adhesive-tape exfoliation, (b) Binarized image of the ink transcribed to the tape through adhesive-tape exfoliation and (c) Overlapping images of (a) and (b)

and the image of the printed characters transcribed to the adhesive tape.

5. Deriving an image of the overlapped binarized images.
6. Quantification of the pixels of the image of the exfoliated printed characters.
7. Identification of the type of printed characters by quantification.
8. The experiment process and results are shown in Figures 3 and 4, respectively.

It was expected that based on the authors' previous experiment report, some of the inkjet-printed characters would be attached and transcribed to the adhesive tape [7]. Different types of adhesive tapes were first experimented with, however, to find an optimal adhesive tape that would allow some of the printed characters to be attached thereto without damaging the original document subject to appraisal. Towards this end, eight kinds of adhesive tape in the market were used in the experiment on exfoliation [23]. The magic tape proved to be the most effective for exfoliation while the highly adhesive tapes damaged the printed characters and paper surface and even got paper fragments transcribed to them, creating problems in accurately comparing the images acquired before and after the exfoliation. The poorly adhesive tapes did not damage the paper surface but were weak in transcribing the ink exfoliation from the printed characters to the tape, making it ineffective for the analysis. It was found that magic tapes have appropriate adhesiveness, making it easy to observe the status of the tape before and after its attachment to the document. As such, they were used in this study [24]. After attaching the tape to the paper surface with inkjet-printed characters for exfoliation, the ink was transcribed to the tape, and the transcribed image was

confirmed on the tape. These images were binarized into the image of the inkjet-printed characters (a) and the image of their transcription to the tape (b). The transcribed area was quantified by the pixel count ratio of the binarized two-area images.

Specimens created using diverse inkjet printers were experimented with using the above method, and the amount of exfoliated ink was quantified as shown in Table 1. As shown in Figure 6, less ink was exfoliated from the old inkjet-printed specimens, and the paper of some of them could be damaged.

Figure 6. Original image of the old inkjet-printed characters exfoliated with adhesive tape. (a) Binarized image of the old inkjet-printed characters before adhesive-tape exfoliation and (b) Binarized image of the ink transcribed to the tape through adhesive-tape exfoliation.

Table 1. Overlap rate of experiment.

Entry	Manufacturer & Product Name	Type	Time	Overlapping Rate
1	Canon pixma MX366	Inkjet	1day	91.28%
2	Canon pixma MP287	Inkjet	1day	86.05%
3	HP Officejet 8600	Inkjet	1day	88.06%
4	HP Officejet 7110	Inkjet	1day	85.90%
5	Epson B-310BN	Inkjet	1day	88.95%
6	Samsung SCX-2000FX	Inkjet	1day	86.06%
7	Samsung SCX-1855F	Inkjet	1day	72.29%
8	LG Lpp 6010N	Inkjet	1day	45.68%
9	Brother MFC J430W	Inkjet	1day	43.84%
10	Canon pixma MX366	Inkjet	2day	90.17%
11	Canon pixma MX366	Inkjet	1 month	85.32%
12	Canon pixma MX366	Inkjet	3 month	84.71%
13	Canon pixma MX366	Inkjet	6 month	81.58%
14	Canon pixma MX366	Inkjet	1 year	78.36%
15	Canon pixma MX366	Inkjet	2 year	45.31%
16	Canon pixma MX366	Inkjet	3 year	40.97%
17	Epson B-310BN	Inkjet	3 year	18.48%
18	HP Officejet 8600	Inkjet	3 year	13.51%
19	Fuxi Xerox Docucentrell 2200	Toner	1 day	0.00%
20	Canon-IR2830	Toner	1 day	0.00%
21	HP Laserjet 2300L	Toner	1 day	0.00%
22	Oki-C530	Toner	1 day	0.00%
23	Konica Minalta bizhub423	Toner	1 day	0.00%
24	Samsung-JC68-03019B	Toner	1 day	0.00%
25	Fuxi Xerox Docucentrell	Toner	3 year	5.91%
19	Canon-IR2830	Toner	3 year	0.91%
20	HP Laserjet 2300L	Toner	3 year	0.85%
21	Konica Minalta bizhub423	Toner	3 year	3.96%

These results suggest the possibility that adhesive tape can be used to judge the relative production time of documents in their appraisal. As there were no 3-year-old specimens, however, such relationship between the document production time and the exfoliation amount could not be accurately revealed, but further experiments will be conducted to determine if appraisal results can be derived even for considerably old specimens, and to determine the relationship between the production time and the exfoliation amount.

Experiments were performed in which toner-printed characters were attached to adhesive tape and exfoliated to see if the toner would be transcribed to the tape. Unlike the inkjet-printed characters, the results revealed that the toner in the printed characters was nearly not exfoliated at all or transcribed to the tape, or that its exfoliated amount was minimal. The experiment results presented in the authors' previous paper revealed that the toner particles that consisted mainly of red stamping ink were nearly exfoliated by the adhesive tape while the toner attached to the paper was strongly attached thereto due to the prevailing heat and pressure conditions, making it difficult to exfoliate it. These results were obtained from the experiments that were performed in this study. Based on the references, it was concluded that heat and pressure are applied to the paper when toner particles are attached to it, and that to exfoliate a large amount of toner, the adhesive tape's adhesiveness alone would not suffice [25].

The specimens produced using six types of toner printer were tested for adhesive-tape exfoliation using the experiment method earlier described, and it was revealed that the toner was nearly not exfoliated at all or only a tiny amount of toner particles was exfoliated, as mentioned above. To observe the toner-printed samples with the passage of time, experiments were performed using four up-to-3-year-old specimens. As shown in Figure 7, the toner was minimally exfoliated from the older samples, but the toner was exfoliated.

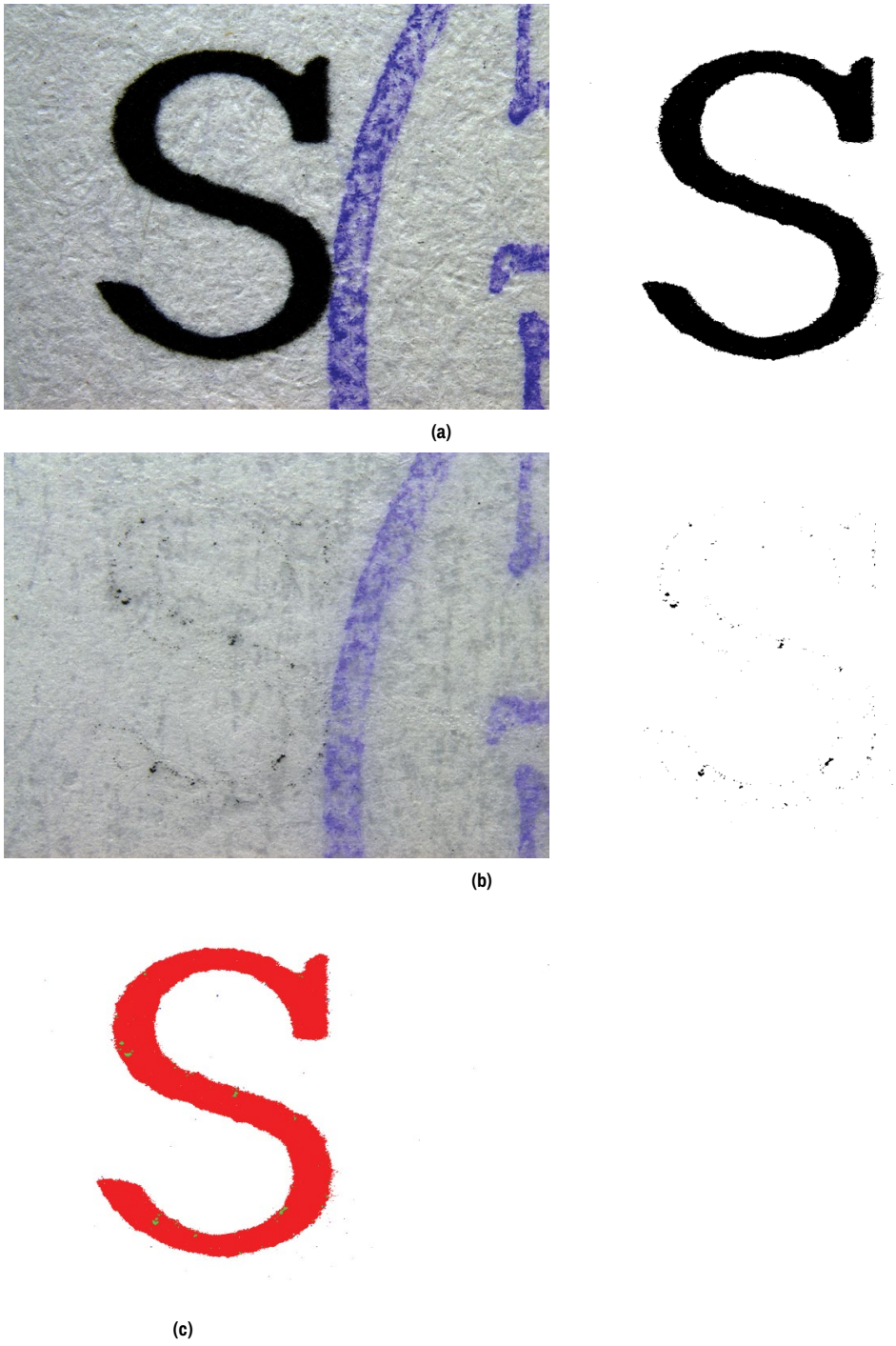

Figure 7. Binarization and quantification of the adhesive-tape exfoliation of old toner-printed characters. (a) Binarized image of the toner-printed characters before adhesive-tape exfoliation, b) Binarized image of the toner transcribed to the adhesive tape after adhesive-tape exfoliation and (c) Overlapping images of (a) and (b).

Conclusion

In this study, inkjet- and toner-printed characters were attached to adhesive tape and exfoliated. Then the image of the printed characters before exfoliation, the image of the printed characters transcribed to the adhesive tape, and their binarized overlapping image were quantified in terms of pixel count to determine the printing method that was used for them. In particular, the method proposed herein makes it possible to analyze and quantify the pixel count through the binarization of images, and to show a clear change in the final image of the printed characters, thus facilitating a comparative analysis of the printed characters, enabling accurate extraction and matching of features, and making it easy to effectively determine any difference between the printed characters before and after exfoliation. In addition, the experiment results could be presented in terms of the exfoliation amount and the change amount of the printed characters of the specimen, together with the images, making it possible to identify diverse printed documents.

For the inkjet-printed characters, an 80-40% overlapping rate was derived from nine printer types. An 80% overlapping rate was shown by the just-printed specimens, but over 3 years, the rate dropped to 40%, revealing that with the passage of time, the exfoliation amount decreases.

Meanwhile, for the toner-printed characters, a 0-2% overlapping rate was derived from the specimens just printed using six printer types, but the overlapping rate for the 3-year-old specimens increased to up to 4%, revealing that with the passage of time, the exfoliation amount increases.

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