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Technical Note

The operating regularity of the stepper motor of thermal inkjet printers and its application in the China national accreditation service 2017ZO146 altered documents identification proficiency test

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ABSTRACT

With the continuous innovation of inkjet printing technology, the methods of using inkjet printers for falsification have also constantly evolved, leading to increasing difficulties in identifying printing alterations made by the same inkjet printer. This paper mainly studies the operating regularity of the stepper motor of inkjet printers to determine the operating mechanism of inkjet printers and thus to identify whether documents had been tampered with. To detect the operating track of the stepper motor, 154 documents printed by 22 different brands and models of thermal inkjet printers were studied according to the periodic morphological characteristics of ink marks and the track of the stepper motor during different printing processes. As a result: ① the maximum gauge of 22 printheads was found to be different and ② the different distribution of ink marks were mainly affected by the direction and speed of the stepper motor. The track of the stepper motor was able to be determined by the periodic morphological characteristics of the ink marks combined with the maximum gauges, and could be used to judge how many times a document was printed. The observed regularities were evaluated by the CNAS 2017ZO146 test, a national proficiency test in China. In conclusion, using the summarized operating regularities of the stepper motor, it is possible to identify printing alterations made by the same thermal inkjet printer.

1. Introduction

With the development of office automation and the increasing popularity of some types of office equipment, printers have become indispensable to the modern office. Among them, thermal inkjet printers have always had a place in the office because they are cost-effective [1]. Along with the spread of inkjet printers, the number of printed documents has increased year by year. In practice, there has been an increasing number of cases in which tampering was performed using inkjet printers [2]. However, technological innovations have significantly improved [3]. For example, the paper feed inside the printers has gradually been stabilized [4], the ink jet nozzles have become more accurate [5], the quality of the ink has been continuously optimized [6], the morphological characteristics of the ink marks have become clearer [7], etc. These factors make it difficult to identify whether printed documents have been tampered with in forensic practice, especially regarding alterations made with the same printer. Because the typographic character of the original content and the added content matches well and the dyes and pigment of ink are identical [8], a general morphological examination of characters [9,10] and the methods used to determine the chemical composition of inks [11,12] are not suitable in such cases.

Although these types of alterations are indeed troublesome, the fact that the stepper motor operates on multiple independent tracks to perform alterations cannot be changed [13], which leaves clues for forensic identification.

Therefore, this paper selected 22 thermal inkjet printers of different brands and models from HP and Canon to study the operating regularity of the stepper motor inside the inkjet printers. The gauges of the printhead were first measured to determine the track distance. Then, the track of the stepper motor in a single row was studied according to the morphological characteristics of the ink marks within different printing processes. Finally, the whole track of the stepper motor was studied to summarize the operating regularities, which were further evaluated by a Chinese national proficiency test for altered document identification.

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Table 1
List of 22 thermal inkjet printers.

Device no.	Brand	Model	Origin
1	HP	Photosmart D5468	U.S.A.
2	HP	Officejet pro6230	U.S.A.
3	HP	Officejet pro8100	U.S.A.
4	HP	Deskjet1112	U.S.A.
5	HP	Deskjet3838	U.S.A.
6	HP	Deskjet4729	U.S.A.
7	HP	AMP	U.S.A.
8	HP	Ink Tank418	U.S.A.
9	HP	Ink Tank419	U.S.A.
10	HP	Envy photo6220	U.S.A.
11	Canon	IP1188	Japan
12	Canon	IP2780	Japan
13	Canon	IP2788	Japan
14	Canon	IP2880	Japan
15	Canon	TS308	Japan
16	Canon	TS5180	Japan
17	Canon	E478	Japan
18	Canon	E518	Japan
19	Canon	E568	Japan
20	Canon	MP288	Japan
21	Canon	MX498	Japan
22	Canon	G4810	Japan

2. Materials and methods

2.1. Devices

An Axio Imager Z2 Vario microscope equipped with an Axiocam HRC CCD (Carl Zeiss MicroImaging GmbH, Göttingen, Germany) was used to observe the morphological characteristics of ink marks and the ink quality of printed documents at 50 times magnification.

A Digital microscope (DSX510, Olympus, Japan) equipped with a CCD (DP73WDR-1-51, Olympus, Japan) was used to take micrographs of the nozzles of the stepper motor at 555 times magnification.

A ruler with a length of 30 cm (No. 8463, Deli, China) was used to measure the maximum gauge of the stepper motors of the printers.

2.2. Inkjet printers

Twenty-two thermal inkjet printers from HP and Canon[1] were studied. The detailed information of these printers is listed in Table 1. Printed documents were prepared by these devices on sheets of Double A copy paper (A4, 80 g/m^2, Prachinburi, Thailand).

2.3. Printed context

One hundred and fifty-four samples from three categories were printed by the twenty-two printers. Twenty-two samples from the first category, as shown in Fig. 1, were used to measure the maximum gauge of the printhead from the twenty-two devices. Forty-four samples from the second category, as shown in Fig. 2, were used to estimate the operating regularities of the stepper motors, two for each device. Eighty-eight samples from the third category, as shown in Fig. 3, were used to produce 4 types of added alteration.

[1] For thermal inkjet printers, Canon and HP have a brand share of 60.2% and 38.1% on Chinese market. Source: ZOL leaderboard, website link: http://top.zol.com.cn/compositor/658/manu_attention.html Access time: July 20, 2019.

Fig. 1. Category 1.

2.4. Measuring method to determine the maximum gauge of the printheads

The stepper motor of the inkjet printer is an electric rail device that carries the printhead and the ink cartridge. The maximum gauge of the printhead is the vertical length of the nozzle arrangement, that is an important characteristic of inkjet printers. Thus, the main measurement methods include:

2.4.1. Direct measurement

The printhead of the inkjet printers were unloaded, and the vertical length of the printhead was measured by a ruler. This measurement result is the theoretical maximum value, which was measured to provide a verification of the vertical length of the printhead measured indirectly.

2.4.2. Indirect measurements

2.4.2.1. Distribution of the sputtered ink dots. The stepper motor of the inkjet printer uses a serial reciprocating mode of operation, and sputtered ink dots often appear alternately on both sides of a character (Fig. 4). Therefore, the maximum gauge of the printhead can be determined through measuring the average vertical distance of adjacent one-side sputtered ink dots (SIDs) [14].

2.4.2.2. Misalignment of the ink marks. In the process of the serial reciprocating movements of the stepper motor inside a inkjet printer, ink marks of adjacent rounds might be displaced due to the misalignment of the printhead (Fig. 5). Therefore, the maximum gauge of the printhead can be determined by measuring the average vertical distance of misaligned ink marks (MIMs) within adjacent misalignments.

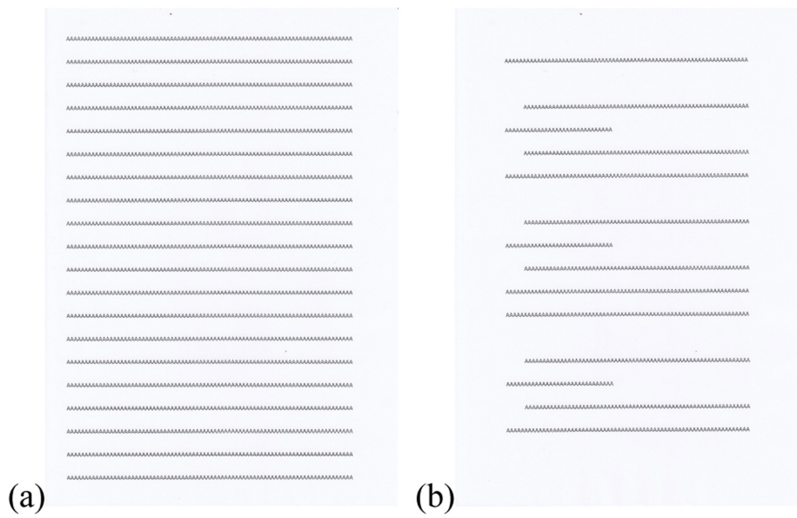

Fig. 2. Category 2, sample (a) is used to examine the track of the stepper motor in a single row; sample (b) is used to examine the track in adjacent rows.

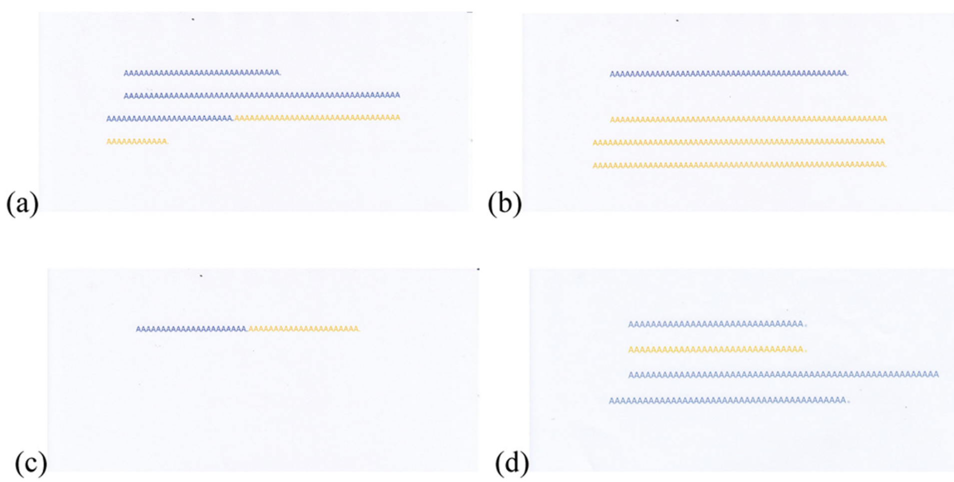

Fig. 3. Category 3, 4 types of added alterations (the original words are marked with dark blue, the added words are marked with yellow): sample (a) and sample (c) are used to examine the added printing in one row, and sample (b) and sample (d) are used to examine the added printing in different rows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

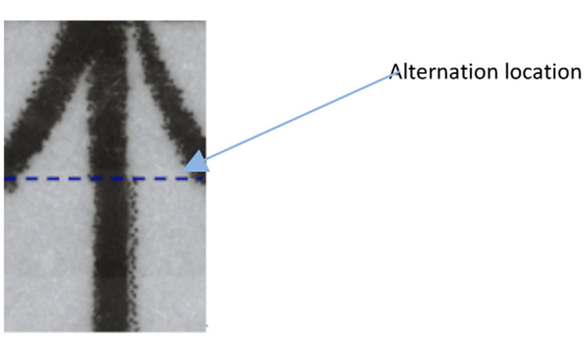

Fig. 4. Alternately appearing sputtered ink dots under the microscope.

2.4.2.3. Gradient of printing quality. In the process of inkjet printing, there are subtle differences at different nozzle locations while the ink slot transports and discharges ink. As reflected on documents with long-term printing, the printing quality of an area with poor discharge is bad, and the morphological characteristics of the ink marks are loose. However, the printing quality of an area with fine discharge is good, and the morphological characteristics of the ink marks are dense (Fig. 6). Therefore, the maximum gauge of the printhead can be roughly measured based on the distribution of printing quality (DPQ) of documents.

2.5. Observation of the operating regularities of the stepper motor

The operating regularities of the stepper motor are used to confirm and re-encode the input signals by the built-in program of the inkjet printer to make the stepper motor operate repeatedly [15] and guarantee the printing efficiency. Documents printed using thermal inkjet printing technology are prone to have a tail (i.e., sputter dots) [16,17]. The direction and speed of the stepper motor were analyzed by observing the morphological characteristics of the sputter dots to summarize the operating regularities.

When the inkjet printers printed the experimental samples, the cover was left open to observe the complete track of the 22 thermal inkjet printers while printing. This process was also recorded by a

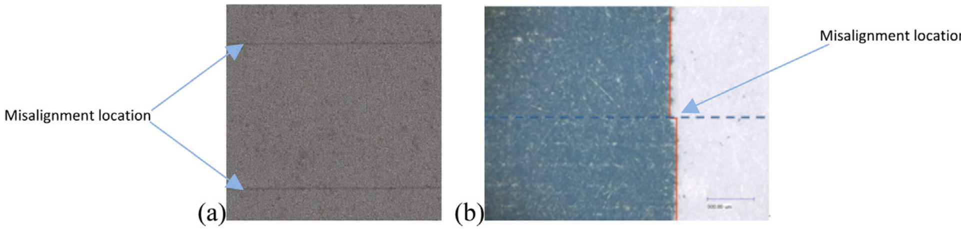

Fig. 5. Vertical misalignment (a) and horizontal misalignment (b) of ink marks under the microscope.

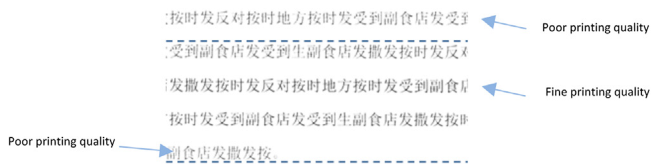

Fig. 6. Distribution of printing quality of a document.

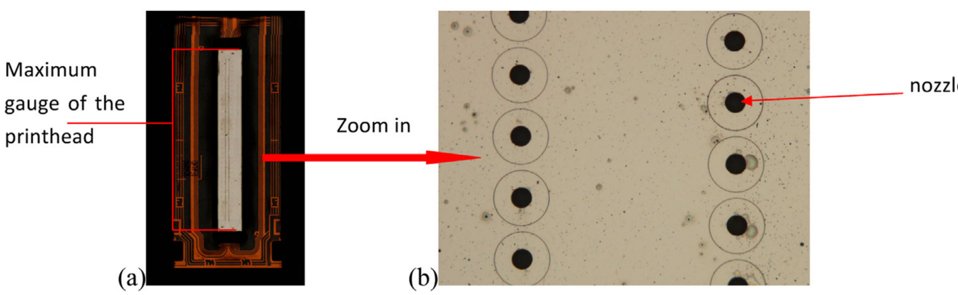

Fig. 7. Schematic of the printhead(a) and nozzle(b).

HUAWEI P9plus (HUAWEI Technologies,Shenzhen, China) mobile phone to compare with the results of the measurement.

3. Result and discussion

3.1. Maximum gauge of the printhead

The maximum gauge of the printhead is the vertical length of the nozzle arrangement. The nozzle is a small hole in which ink is heated or pressurized to be ejected from the printhead, and most nozzles are arranged in a unique manner to form a nozzle group (Fig. 7). The maximum gauges of the black printhead from the 22 thermal inkjet printers measured in this paper are listed in Table 2.

Among the thermal inkjet printers studied in this paper, the maximum gauges of all the integrated ink cartridges and some separate cartridges could be directly measured by disassembling the printhead, but other separate ink cartridges could only be indirectly measured because the printhead inside the printer could not easily be disassembled. From the data presented in Table 2, the maximum gauge of the printhead determined through measuring the average vertical distance of the SIDs of one side and the average vertical distance of the MIMs are slightly shorter than those of the direct measurement. Meanwhile, because the gradient period of printing quality is difficult to determine in printed documents, the maximum gauge of the printhead estimated measurement based on the DPQ cannot be achieved successfully and accurately, as the data can only be presented in ranges.

Table 2
List of the maximum gauge (mm) of the black printhead from 22 thermal inkjet printers.

Device	Method			
	Direct measurement	Indirect measurement		
		SIDs	MIMs	DPQ
1. HP Photosmart D5468	15.5	15.0	15.0	14–16
2. HP Officejet pro6230	/[a]	23.0	23.0	21–25
3. HP Officejet pro8100	/[a]	29.0	29.0	28–31
4. HP Deskjet1112	14.0	14.0	14.0	14–16
5. HP Deskjet3838	14.5	14.5	14.5	/[b]
6. HP Deskjet4729	15.5	15.0	15.0	/[b]
7. HP AMP	14.5	14.0	14.0	/[b]
8. HP Ink Tank418	14.5	14.0	14.0	/[b]
9. HP Ink Tank419	14.5	14.0	14.0	/[b]
10. HP Envy photo6220	16.0	15.5	16.0	14–18
11. Canon IP1188	15.0	14.5	14.5	14–18
12. Canon IP2780	14.0	14.0	14.0	/[b]
13. Canon IP2788	15.0	14.5	14.5	/[b]
14. Canon IP2880	14.0	14.0	14.0	/[b]
15. Canon TS308	15.0	15.0	14.5	/[b]
16. Canon TS5180	14.0	14.0	14.0	/[b]
17. Canon E478	14.5	14.5	14.5	/[b]
18. Canon E518	14.5	14.5	14.5	/[b]
19. Canon E568	14.0	14.0	14.0	/[b]
20. Canon MP288	14.5	14.5	14.5	/[b]
21. Canon MX498	15.0	15.0	15.0	/[b]
22. Canon G4810	15.0	14.5	14.5	/[b]

[a] The printers use separate ink cartridges, so the gauge cannot be measured.
[b] Cannot detect because no obvious gradient period of printing quality was observed.

The maximum gauges of the stepper motors from devices with integrated ink cartridges are between 14 mm–16 mm, with slight differences. However, the maximum gauges of the stepper motors from devices with separate ink cartridges show large differences, such as HP Photosmart D5468 (15 mm), HP Officejet pro6230 (23 mm) and HP Officejet pro8100 (29 mm).

3.2. Operating regularities of the stepper motor

The similar regularities of the 22 devices under default settings were observed on the inkjet printed documents. These regularities include the track of the stepper motor in a single row and adjacent rows. Through these regularities and the morphological ink marks of documents, the whole track of the stepper motor can be deduced.

3.2.1. Track of the stepper motor on a single row

Normally, the stepper motor needs to go through five steps of starting, accelerating, stabilizing, decelerating and suspending when operating in a single row, which means the printhead also undergoes at least two stages of acceleration and deceleration. In a single row, the sputtered ink dots are normally on one side of the character. Changes of the operating speed will cause the speed of the ink droplet to change along with the operating direction. Therefore, morphological differences of sputtered ink dots form in different operating statuses. Take the HP Deskjet 1112 as an example (Fig. 8).

In a single direction, the stepper motor operates at a slow speed during the starting and suspending phases, as shown in Fig. 8(a),(e). The number of sputtered ink dots around the characters in those phases is loose and close to the strokes. However, while the stepper motor operates in the high-speed phase, as shown in Fig. 8(b)–(d), the number of sputtered ink dots around the characters is dense and scattered outside the strokes. We thus conclude that by observing the morphological characteristics of the sputtered ink dots around the character, it is possible to determine the starting and terminal point of the stepper motor operating in a single direction, and together with the measured maximum gauge of the printhead, the track of the stepper motor on a single row can be determined. And by comparing the morphological differences of ink dots around each character, it is feasible to roughly determine the accelerating and decelerating phases of the stepper motor.

3.2.2. The whole track of the stepper motor

The whole track of the stepper motor refers to the track of the starting point to the destination of the stepper motor operating during the process of printing a single page. Normally, the whole track of the stepper motor contains several single rows, which

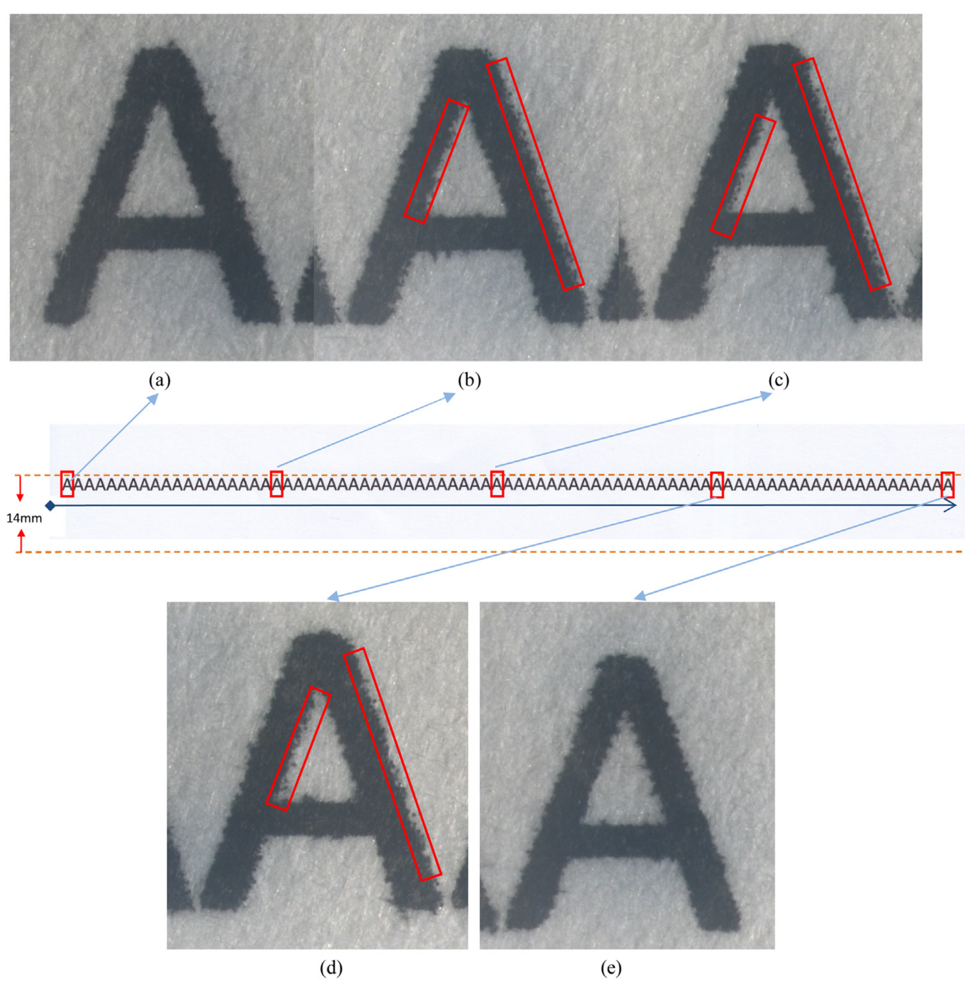

Fig. 8. Microscopic images of the (a) starting position, (b) accelerating position, (c) stabilizing position, (d) decelerating position and (e) suspending position in the track of the stepper motor on a single row from device No. 4, HP Deskjet 1112 (the track of the stepper motor is marked with a dark blue arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

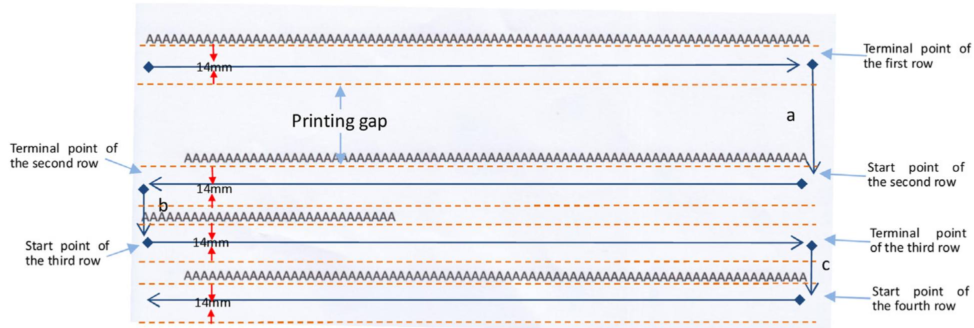

Fig. 9. Printing gap (a), starting and terminal point positions between adjacent rows (b),(c) during the operation of the stepper motor from device No., 4 HP Deskjet 1112 (the whole track of the stepper motor is marked with a dark blue arrow, and the maximum gauge of the printhead is marked with a red arrow, which is approximately 14 mm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

indicates that to determine the whole track of the stepper motor, it is necessary to determine the connection position of the adjacent row of the stepper motor based on the known trajectories from each single row. Some regularities of the stepper motor when operating connection positions between adjacent rows are summarized (Fig. 9): first, the stepper motor serially prints a single page from top to bottom; second, the stepper motor suspends when a printing gap appears, while the roller continues to feed paper until the stepper motor starts the next track of printing; and third, the terminal point of the stepper motor depends on the starting point of the next row, unless the print width of the previous row is wider.

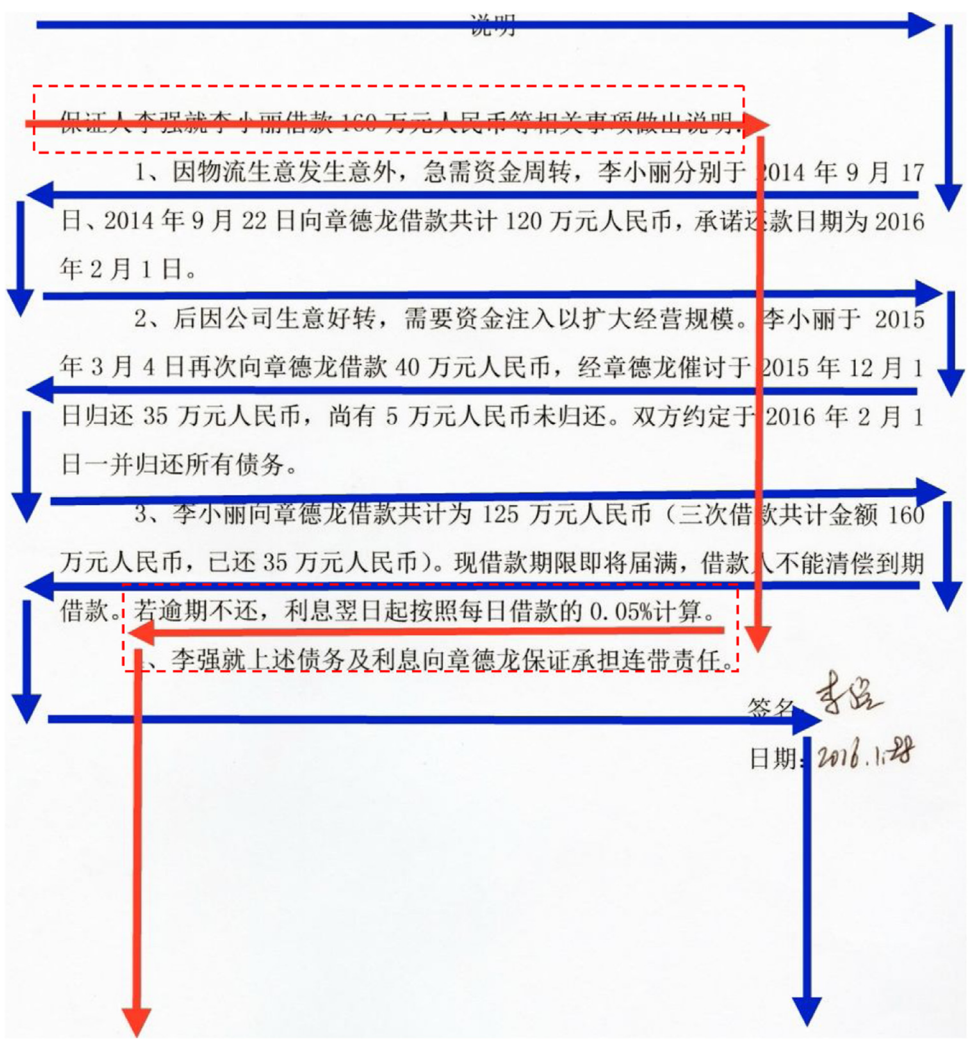

Fig. 10. Sample of the CNAS 2017ZO146 Altered Documents Identification Proficiency Test (the first track of the stepper motor is marked with dark blue arrows, and the second track of the stepper motor is marked with red arrows). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

4. Application

This paper used the sample of CNAS 2017ZO146 Altered Documents Identification Proficiency Test (Fig. 10) as a typical example to evaluate the observed regularities of the stepper motor of thermal inkjet printers.

CNAS (China National Accreditation Service for Conformity Assessment) proficiency testing is an internationally recognized means of quality control. It is widely used by most regulatory agencies, industry organizations or laboratories in China. One hundred and ten forensic institutions participated in the CNAS 2017ZO146 Proficiency Test.

The sample production process was as follows: First, all of the text was edited by using Microsoft Office Word software. Secondly, the color of the text in the red dotted line box was set to white, and the text outside the red dotted line box was set to black; the text was printed by a Canon IP2880 inkjet printer. Thirdly, the color of the text in the red dotted line box was set to black, and the text outside the red dotted line box was set to white; the text was printed by the same printer to form an added text. There were altogether three added printing alterations.

As a result, 54.5% of the participants received “satisfied” remark from the reviewing experts, as they found at least two added printing alterations. 31% of the participants received “pass” evaluation, as they found at least one but not all added printing alteration. 14.5% of of the participants received “fail” evaluation, because they only found at most one added printing alteration and there were significant errors in the expressing. Although 38.2% of the participants who got “satisfied” evaluation found all three added printing alterations by morphological examination, the analysis of how the added printing were formed was inaccurate in general, for the operating regularities of the stepper motor in inkjet printers was not clearly and fully understood.

Based on the methods described above, there were three aspects to evaluate with the CNAS 2017ZO146 test:

(1) Estimate the gauge of the black printhead from the inkjet printer based on the words of non-contentious contents through the SIDs.
(2) Observe whether the distribution of sputtered ink dots is different due to the opposite operating directions of the stepper motor between adjacent rows.
(3) Observe the corresponding position of the starting and terminal points between adjacent rows of the stepper motor on the sample.

4.1. Normal printing

In normal inkjet printing, the distribution of the sputtered ink dots is on one side of the character when the stepper motor operates in a single direction. The operating connection position between adjacent rows is the terminal point of the first row and the terminal point of the second row (Fig. 11).

Through morphological microscopic observation, in the red frame of Fig. 11, the sputtered ink dots around the Chinese characters "万" and "有" were distributed on the left side of the strokes and the sputtered ink dots around the Chinese characters "需" and "务" were distributed on the right side of the strokes, which shows that the gauge of the stepper motor was approximately two rows of characters (approximately 14 mm). No obvious sputtered ink dots were distributed around the Chinese characters "年","日" and the numeral character "1″, which shows that the operating connection position between adjacent rows was the terminal point of the first row and the starting point of the second row.

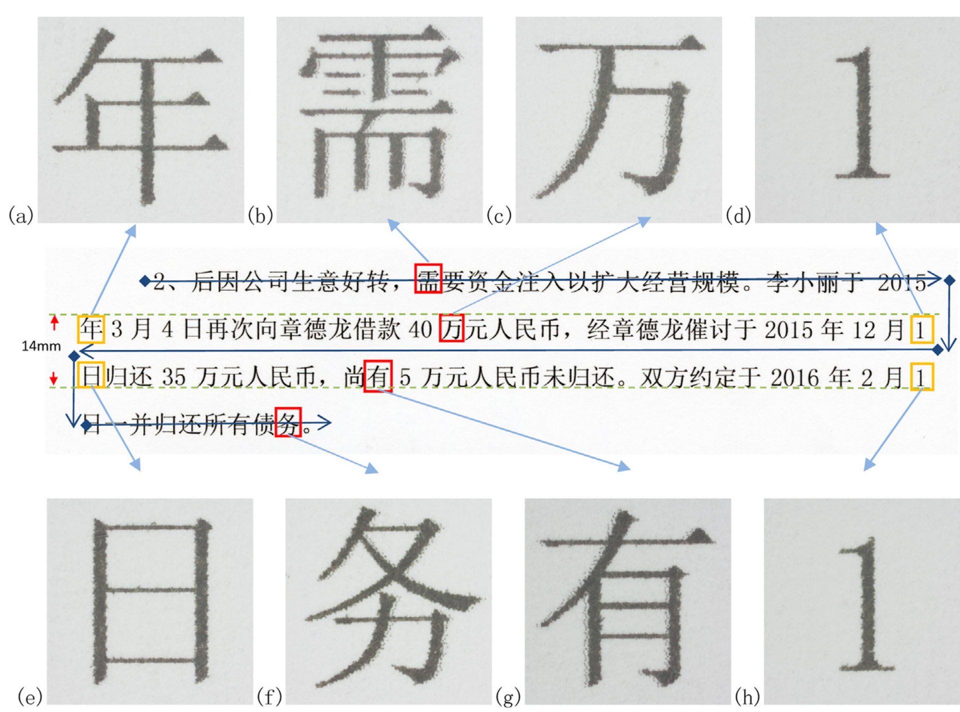

Fig. 11. Non-contentious contents of the sample of CNAS 2017ZO146 test (the track of the stepper motor is marked with dark blue arrows, and the maximum gauge of the printhead is marked with red arrows, which is approximately 14 mm) and (a) the Chinese character "年", (b) the Chinese character "需", (c) the Chinese character "万", (d) the numeral character "1″, (e) the Chinese character "日", (f) the Chinese character "务", (g) the Chinese character "有" (h), and the numeral character "1″ under the microscope at a magnification of 50×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

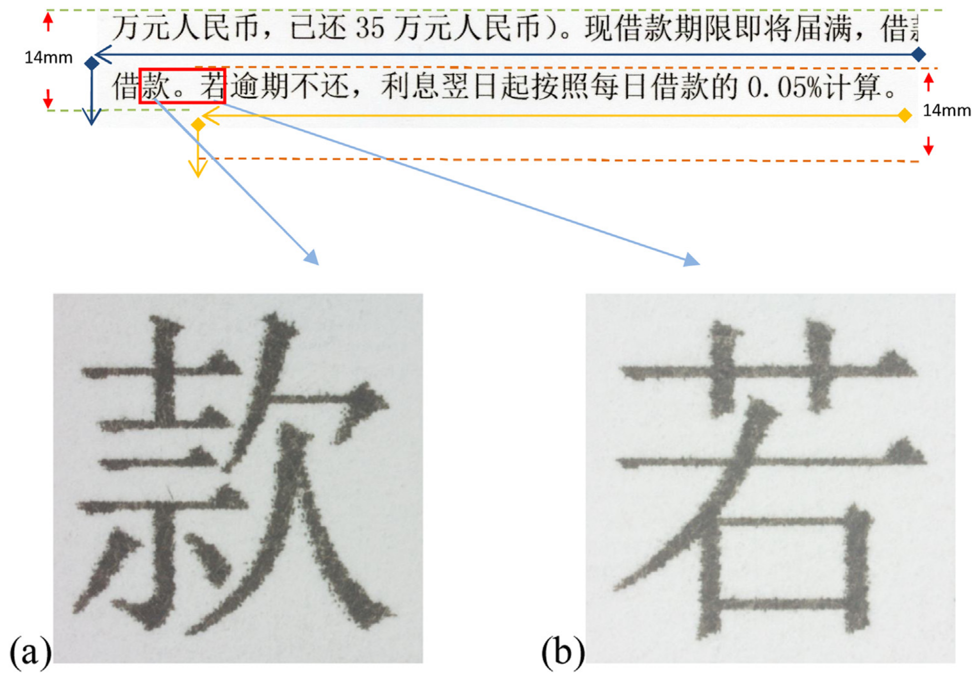

Fig. 12. Partial screenshot of the sample of the CNAS 2017ZO146 test (the first track of the stepper motor is marked with a dark blue arrow, the second track of the stepper motor is marked with a yellow arrow, and the maximum gauge of the printhead is marked with a red arrow, which is approximately 14 mm.), and (a) the Chinese character "款" and (b) Chinese character "若" under the microscope at a magnification of 50×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

4.2. Added printing alteration in one row

4.2.1. Abnormal distribution of sputtered ink dots between adjacent characters

Through morphological microscopic observation, in the red frame of Fig. 12, we found that the sputtered ink dots around the Chinese character "款" were distributed on the left side of the strokes, and no obvious sputtered ink dots were distributed around the Chinese character "若", which did not correspond to the distribution regularity of the sputtered ink dots when the stepper motor was operating on single row.

4.2.2. Abnormal position and quantity of the starting and terminal point

Through the morphological microscopic observation, in the red frame of Fig. 13, we found that there were no obvious sputtered ink dots around the Chinese characters "借" and "若" because the operating direction of the stepper motor was to the left, which means the Chinese characters "借" and "若" were both the terminal point of this single row. These two terminal points did not correspond to the regularity of the position and quantity of the starting or terminal points when the stepper motor was operating on single row.

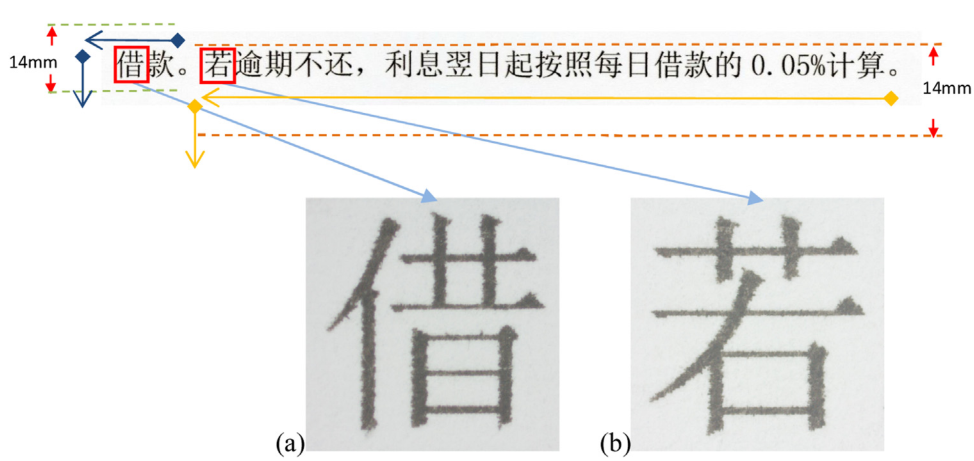

Fig. 13. Partial screenshot of the sample of the CNAS 2017ZO146 test (the first track of the stepper motor is marked with a dark blue arrow, the second track of the stepper motor is marked with a yellow arrow, and the maximum gauge of the printhead is marked with a red arrow, which is approximately 14 mm.), and (a) the Chinese character "借" and (b) the Chinese character "若" under the microscope at a magnification of 50×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

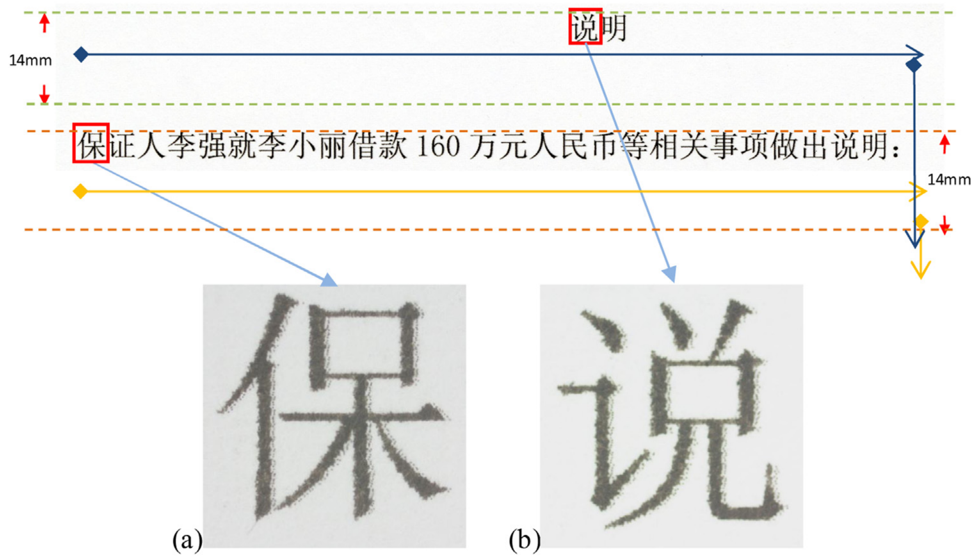

Fig. 14. Partial screenshot of the sample of the CNAS 2017ZO146 test (the first track of the stepper motor is marked with a dark blue arrow, the second track of the stepper motor is marked with a yellow arrow, and the maximum gauge of the printhead is marked with a red arrow, which is approximately 14 mm.), and (a) the Chinese character "保" and (b) the Chinese character "说" under the microscope at a magnification of 50×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

4.3. Added printing alteration in different rows

4.3.1. Abnormal distribution of sputtered ink dots between characters of adjacent rows

Because the stepper motor is operating in the opposite direction when printing adjacent rows, the sputtered ink dots of characters from adjacent rows are distributed on different sides.

Through morphological microscopic observation, in the red frame of Fig. 14, we found that the sputtered ink dots around the Chinese characters "保" and "说" were both distributed on the right side of the strokes, which means the operating directions of the stepper motor in adjacent rows were both to the right., which did not correspond to the distribution regularity of the sputtered ink dots when the stepper motor was operating on adjacent rows.

4.3.2. Abnormal position of the cohesive point from adjacent rows

The starting and terminal points of the stepper motor on adjacent rows are interrelated with each other. That is, the stepper

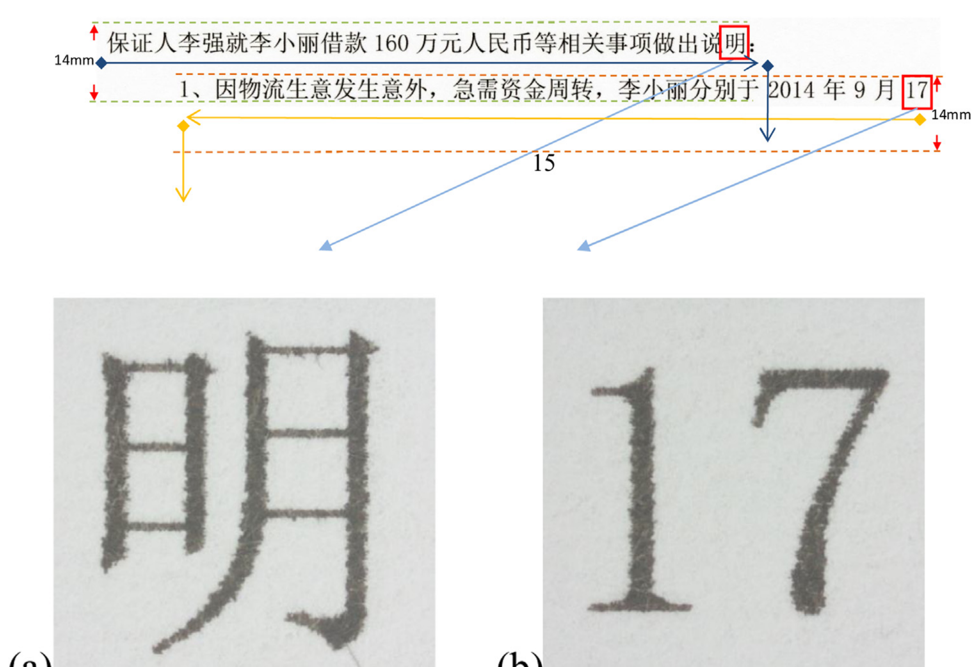

Fig. 15. Partial screenshot of the sample of the CNAS 2017ZO146 Altered Documents Identification Proficiency Test (the first track of the stepper motor is marked with a dark blue arrow, the second track of the stepper motor is marked with a yellow arrow, and the maximum gauge of the printhead is marked with a red arrow, which is approximately 14 mm), and (a) the Chinese character "明" and (b) the numeral character "17" under the microscope at a magnification of 50×. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

motor stays in the same horizontal position when it operates at the terminal point of the previous row and the starting point of the next row.

Through morphological microscopic observation, in the red frame of Fig. 15, we found that there were no obvious sputtered ink dots around the characters "明" and "17″, which means the Chinese character "明" was the terminal point of the previous row and the numeral character "17" was the starting point of the next row. However, there was a clear gap between their horizontal positions that did not correspond to the regularity of the position of the cohesive point when the stepper motor was operating on adjacent rows.

It was clear there was multiple operating tracks on the questioned document of CNAS 2017ZO146 test. It was proved to be an altered document that included alterations made with the same machine, which added a declaration of joint liability of the loan with high interest to a third person. According to the morphological characteristics of the ink marks left on the printed documents, combined with the operating regularity of the stepper motor, the added text of the questioned document can be inferred.

5. Conclusions

In this paper, through experiments performed on 22 thermal inkjet printers, the operation of the stepper motor inside the thermal inkjet printers is shown to have regularities. According to the various periodic morphological characteristics of the sputtered ink dots distributed around characters on printed documents, combined with the maximum gauge of the stepper motor, the operating track can be determined. With CNAS 2017ZO146 Proficiency Test as an example, the operating regularities of the stepper motor summarized in this study were proved to be applicable. They can be used to identify the printing alterations of documents made by the same thermal inkjet printer in forensic practice.

CRediT authorship contribution statement

Chen-Jun Ma: Methodology, Data curation, Writing - original draft, Investigation, Funding acquisition. **Qing-Hua Zhang:** Validation, Funding acquisition. **Qi-Ran Sun:** Writing - review & editing. **Xiao-Hong Chen:** Resources, Writing - review & editing, Funding acquisition. **Xu Yang:** Conceptualization, Supervision, Funding acquisition.

Declarations of Competing Interest

None.

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