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The State-of-the-Art Technique for Determining the Identity and Uniqueness of Common Color Laser Printouts by Coded Dot Matrix Patterns

CrossMark

أحدث تقنية لتحديد هوية وفردية المطبوعات الليزرية الملونة الشائعة باستخدام أنماط المصفوفات المشفرة

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Abstract

Recently, in forensic science studies, identification of the source of color laser printouts is one of the most challenging issues that hinder forensic document examiners. Although various methods for establishing the identity of the source of color laser printouts are currently available worldwide, none of those methods approaches an accuracy and precision of 100%.

The coded dot matrix patterns are state-of-the-art prototypes of steganography based on the active technique. Upon tracking the coded dot matrix patterns of all investigated color laser printouts, the identity and uniqueness can be determined, respectively.

In the current paper, nineteen variant brands of color laser printer machines were selected. The advanced security features embedded in their printouts have steganalysis and grouped them into two broad categories. A direct model of hyperspectral analysis integrated with video spectral comparator Regula® 4307 was applied.

The complete identification of the investigated color laser printouts was achieved. The decisive degree of the results reached one hundred percent for the investigated color laser in this study. Moreover, the novel classification scheme of coded dot matrix patterns presents for completing the individual characteristics.

Keywords: Forensic science, forensic document analysis, color laser printouts, coded dot matrix patterns, hyperspectral analysis.

المستخلص

في الآونة الأخيرة، في دراسات الأدلة الجنائية يُعد تحديد مصدر المطبوعات الليزرية الملونة واحدة من أكثر المشكلات التي تعوق فاحصي المستندات الجنائية. وعلى الرغم من توافر طرق مختلفة لتحديد هوية المطبوعات الليزرية الملونة حالياً في كافة أنحاء العالم فإن أياً من هذه الطرق لم تحقق نسبة 100% في دقة نتائجها.

وتُعد أنماط المصفوفة النقطية المشفرة من أحدث الأنماط للتخفي والتي تعد وسيلة أساسية للتعقب.

وعند تعقب أنماط المصفوفات المشفرة لجميع المطبوعات الليزرية الملونة التي تم دراستها تمكنا من تحديد كل من الهوية والفردية، على الترتيب. وفي الورقة البحثية الحالية تم اختيار عدد تسع عشرة ماركة تجارية لآلات طباعية ليزرية ملونة مختلفة.

وتم تحليل كافة الأنماط الأمنية المطبوعة للمخرجات الطباعية الليزرية الملونة وتقسيمها إلى فئتين كبيرتين. كما تم تطبيق طريقة مباشرة للتحليل فوق الطيفي المدمج بجهاز ريجيولا موديل 4307.

وتم عمل تحديد كامل لكافة المخرجات الطباعية الليزرية الملونة التي تم دراستها.

وبلغت نسبة الدقة في النتائج مئة بالمئة للماركات التجارية للآلات الطباعية الليزرية الملونة التي تم فحصها في هذه الدراسة. علاوة على ذلك، تم عرض مخطط مبتكر جديد لأنماط المصفوفات المشفرة يوضح الخصائص الفردية لتلك الأنماط المشفرة.

الكلمات المفتاحية: علوم الأدلة الجنائية، تحليل المستندات الجنائي، المطبوعات الليزرية الملونة، أنماط المصفوفة النقطية المشفرة، تحليل الطيف الفائق.

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1. Introduction

Printer forensics is a sub-branch of digital forensic science that encompasses the identification of the source of any printouts by different means [1]. All over the world, the standard strategies applied for printer identification are classified into passive and active modes [2–5]. The passive mode, including the intrinsic features, accompanied the printer machines and was named an intrinsic signature [5–7]. The intrinsic signatures are artifacts that may be created via optical, electrical, or mechanical limitations of the printer machines [8–10]. This strategy is utilized in monochromic and color laser printers [2–5, 11]. For an active mode, all extrinsic features embedded in printed documents are explored [12–16]. The extrinsic signature is only utilized for the identification of color laser printers [2, 3, 17, 18]. The extrinsic signatures embedded in a color laser printout fall in the category of steganography [2, 3].

Steganography is the art and science of hiding information within cover media (printed documents) without attracting the attention of a common reader [2, 4, 12]. Therefore, steganography is an advanced technology applied to the security of color laser printing processes [8, 9, 19]. The coded dot matrix patterns (CDMP) are state-of-the-art prototypes of steganography based on the active technique [2, 3, 11]. The coded dot matrix patterns may also be referred to as machine identification code [15, 16] or Counterfeit Protection System. Yellow nano-sized dots are spread across the entire printed paper and are used to identify the printer's source. [2, 15, 18, 19].

For pattern analysis, the class and individual characteristics are the backbones of the complete identification of any pattern. In the class characteristics, some common features are figured generally to describe the identity of patterns. The individual characteristics, on the other hand, represented a peculiar feature for specific one pattern only. Therefore, both class and individual characteristics are complementary to each other. With a comparison of two strategies applied to accomplish complete identification of the source of color laser printouts, the active strategy is a versatile one because it reaches a conclusive accuracy percentage (100%) [4].

In the current paper, the detection of the hidden messages printed in digital media is applied by the steganalysis tool by the video spectral comparator (VSC) Regula® 4307 as a direct technique. The hyperspectral analysis of the image is utilized newly in direct mode to color laser samples. An image processing manipulation or sample preparation is not required. In the investigated images, detection occurred to track the hidden information of printed color documents. In the previous related works in this area, the coded dot matrix patterns were unveiled via an indirect method that required image processing for a soft copy of samples [2, 3, 11]. On the other hand, in the current paper, a direct technique is applied in a non-destructive mode to determine the extrinsic features presented in the candidate's color laser printouts of variant brands on hard copy samples immediately.

The current work in this paper focuses on three aspects: shape, configuration, and distribution of the repeat-coded dot matrix patterns corresponding to all candidate brands of the color printer samples. Upon the regularity and irregularity of shapes of the coded dot matrix patterns, the novel classification was introduced to facilitate and enable forensic document examiners to segregate between different types of color laser printing machines more swiftly and accurately. The individual characterization applied with definite accuracy procedures reached the highest percentage.

2. Materials and Methods

In the current study, the procedural scheme includes the following processes: printing, exposing to hyperspectral analysis, extracting, classification, and identification, respectively, as depicted in Fig. 1. In each process, the implementation, and accomplishment of a direct piece of the procedure should occur before the transfer into the next stage.

2. 1 Printing

In this step, different hard copy sources of color laser printouts of variant brands were obtained. The printing machines included the following brands: Xerox, Dell, Epson, Hewlett-Packard, Toshiba, Panasonic, Kyocera, OKI, Utax, Ricoh, NRG, Gestetner, Savin, Rex Rotary, Xante, Lexmark, Sharp, Canon, and Konica Minolta. One thousand three hundred forty-three (1343) hard copies, containing images and texts, were printed on A4 white papers. Five color laser printouts were printed at different intervals from each color laser printer machine. The passive security features, existing in the color laser printing machines, are transferred onto the printed paper sheet specimens. All details about the color laser printing machines used in this study are presented in Table 1.

2. 2 Exposing to the hyperspectral analysis technique

Video spectral comparator Regula model 4307 supports a set of light sources of visible, infrared, and ultraviolet spectral ranges along with imaging filters used for carrying out forensic examinations Fig. 2.

2. 2. 1 Direct method procedures

All color laser printout specimens were placed without any prior preparation directly onto the XY translation stage to achieve a high-performance positioning along multiple axes (X, Y) and image stitching of Regula 4307 Fig. 3.

2. 3 Extracting

The extraction step is the keynote of the proposed technique. In this step, all captured and saved images from VSC Regula 4307 were scrutinized for their state of uniformity.

All specification parameters applied for all specimen printouts are given in Table 2.

2. 4 Classification

The classification is concerned with three pivotal objects: shape, configuration, and distribution of the

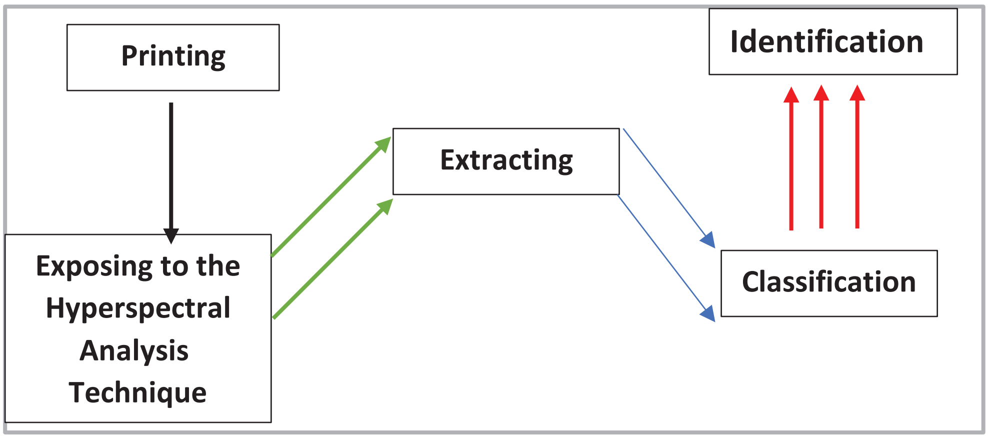

Figure 1. *The schemed steps proposed for the identification approach.*

Table 1- *The different brands and models of investigated color laser machines*

No	Brand	Model	Printouts
1	Xerox (25)	Phaser 6700DN, 6500N, 6000N, workCenter 7345PS, 7675PS, 7228, 6515, 7220, 7855, 7132, 7665, 7645, DocuColor 250, SC 2020, Versant 180 Press	150
2	Dell (7)	5100cn, 3110cn, 1320c	20
3	Epson (3)	Aculaser C4000, C3000, C1100	15
4	HP (50)	Pro M452dn, M254dw, 4700dn, CP6015, CM4730MFP, CP2020, CM4540, 4650, 4600, 3800, 3600, CP1525n, CP4005n, CP2025dn, CM2320MFP, CM4540MFP, CP3520	200
5	Panasonic (4)	DP-C262	20
6	Toshiba (12)	e-studio 3540c, 4540cse, 2023c, 3520c,2820c, 4520c, 2330c, 3505AC, 3005AC, 2010AC	35
7	Kyocera (5)	TASKalfa 250ci, 400ci, 552ci, FS-C5020N	25
8	Utax (2)	CLP 3630	10
9	OKI (2)	Pro1040, Pro9542	10
10	Ricoh (150)	Pro C5200s, Pro C7200x, MP C6000, MP C4500, MP C4501, MP C7500, MP C2500, MP C2800, MP C2550, MP C2551, MP C300, MP C305, SP C430DN, SP C420DN, SP C410DN, SP C320DN, SP C242SF, SP C232SF, SP C231N, SP C242DN, SP C312DN, SP C232DN, SP C311N, SP C222SF, SP C222DN, SP C250DN, SP C252SF, SP C252DN	550
11	Nashuatec (20)	SP C410DN, SP C222DN, MP C3500, MP C4000	100
12	Gestetner	MP C2050, SP C420DN, SP C410DN	30
13	Savin (2)	SP C262DNw, CLP35	6
14	Rex Rotary (2)	MP C2011SP, MP C3004SP	20
15	Xante (2)	IMPRESSIA	20
16	Lexmark (9)	XC2132, C530, C752, C760, C750, C510	30
17	Sharp (3)	MX-2301N, MX-3100N, MX-4071	15
18	Canon (6)	IR C2880i, IR C3080i, C700, C800, C5235i, C5200	30
19	Konica Minolta (10)	C1085, C1060, C1070, 1052, 1250P, C452, C552, C3070, C6085	60

Figure 2- *The integrated video spectral comparator Regula 4307 is connected to the complementary stereomicroscope and supported by a desktop central processing unit.*

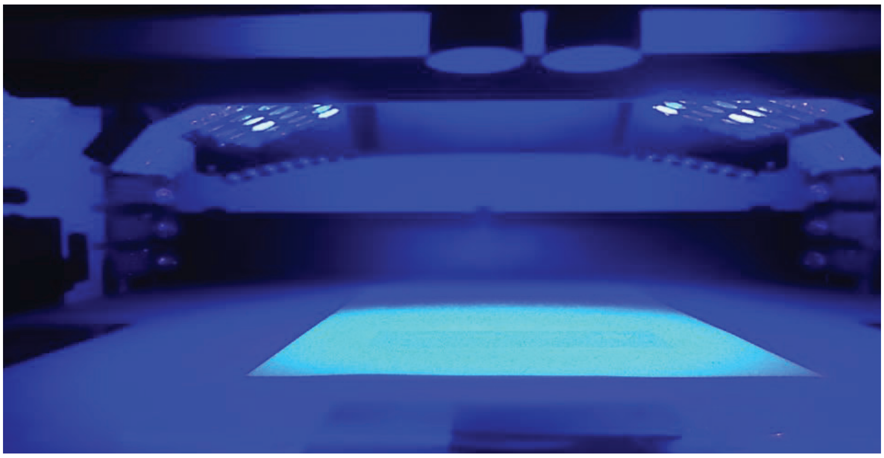

Figure 3- *The XY translation stage of VSC Regula 4307 was activated with the selected wavelength of the hyperspectral imaging technique.*

tracking coded dot patterns. Afterward, the novel classification of the extracted coded dot matrix patterns was based on the regularity of their configurations.

2. 5 Identification

After completing the classification step, identification of the dot matrices printing machine (the source) is the final procedural step. At this stage, the basic iterated code dot matrix was obtained from all candidate-coded dot matrix patterns of different brands. Therefore, this stage accurately determines the regions corresponding to both the class and individual characteristics of each investigated color laser printout.

3. Results and Discussion

3.1 Methodology of work

All investigated color laser printers had tracking dot matrixes spanning the entire prints. Based on the regularity in the iterated coded dot matrix patterns (CDMP), we classified them into two broad categories. The first category comprised five regular shapes with defined configurations and different distributions inside each CDMP. The second category was assigned to three irregular patterns with inconsistent configurations and varying distributions inside each CDMP.

Table 2- *The specific parameters applied on the investigated printouts by Regula® 4307*

The applied parameter	The specific parameter condition
Visualization type	Hyperspectral analysis reflected light
Main device	Regula 4307
Connection variant	Extra Full HD mode
Camera	The main camera of 4307
Zoom	x5.00
Aperture	f 2.8
Focus	3203
Exposure	60
Gain	8
Red balance	0
Green balance	0
Blue balance	0
Increased sensitivity	no
Light source	Hyperspectral analyzer
Wavelength	to 460 nm 420

3. 2 The regular category

In the regular category, seventeen different brands were grouped into five discriminated patterns of coded dot matrix: Xerox, Dell, Epson, HP, Toshiba, Panasonic, OKI, Utax, Kyocera, Ricoh, Nashuatec, Gestetner, Savin, Rex-Rotary, Xante, Lexmark, and Sharp all belonged to regular category Table 1. Moreover, the complete characterizations of these brands will be shown in the following scenarios.

3. 2. 1 The first regular coded dot matrix pattern (Pattern I)

Hewlett-Packard (HP), Toshiba, Panasonic, OKI, Utax, and Kyocera were the objective brands for this category exhibiting typical prototype characteristics of this class.

The prototype of this class has certain specific features that can be summarized as viz:

i. All printed coded dot matrix patterns were grouped horizontally and vertically in rows and columns.
ii. Both horizontal rows and vertical columns were composed of the iterated coded dots matrix pattern.
iii. The distances around each iterated coded dot matrix pattern were constant, and there is no space corresponding to another pattern.
iv. Each iterated coded dot matrix pattern was separated from another one (horizontally and vertically) by two sets of three upright dots. These sets were located on the upper corners of each pattern.
v. Each iterated coded dot matrix pattern had a well-defined configuration composed of sixteen vertical columns and twenty horizontal rows.
vi. Inside each iterated coded dot matrix pattern, column number eight and row number

five were empty of the tracking dots.

vii. The corrected orientation of the iterated coded dot-matrix pattern depends on the orientation of the three upright dots that were located above them Fig. 4.

Fig. 4 shows that all the corporate features of all six brands for the first regular coded dot matrix pattern were visualized accurately.

At this level, the determination of Pattern-I class characteristics was achieved according to the defined configuration. However, the uniqueness of each brand of a printer had the corresponding coded dot matrix pattern determined by different distributions of the tracking dots inside their matrix patterns (individual characteristics).

Furthermore, in Fig. 4, the first four rows of the HP brand are marked with green color and found constant. In the distributions of the coded dot matrix of the same color laser machine, there is no noteworthy change in the distribution positions of the dots at different times.

The identity of HP, Toshiba, Panasonic, OKI, Utax, and Kyocera brands, was determined with well-defined shapes composed vertically of sixteen columns and twenty rows horizontally. The uniqueness of Hewlett-Packard (HP), Toshiba, Panasonic, OKI, Utax, and Kyocera brands, was determined from the constant distributions of the dots at the first

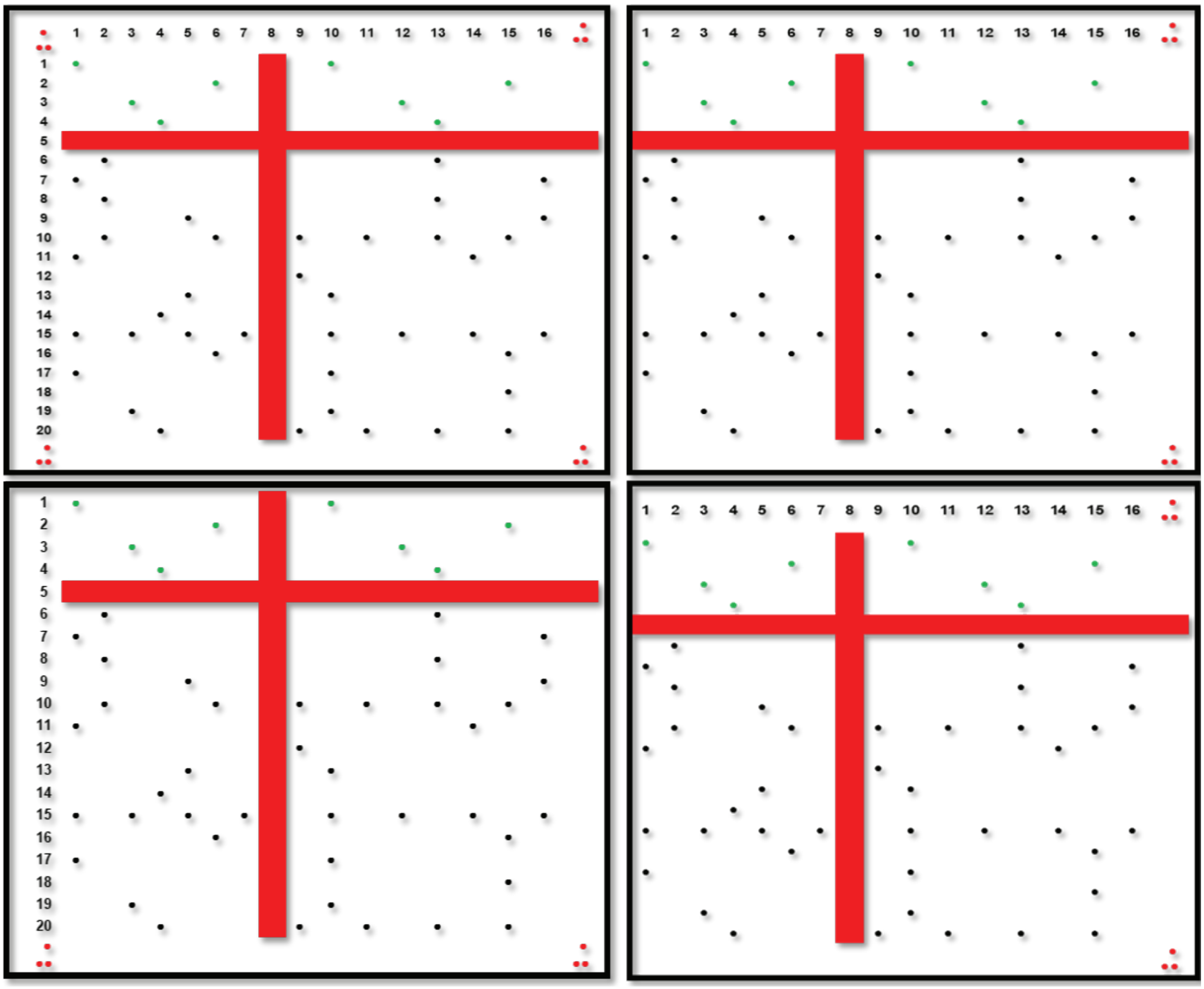

Figure 4- *The simulated form of four repeated coded dot matrix patterns for color laser printout of Hewlett-Packard brand.*

four rows and the different distributions of coded dots matrix below the sixth row of each other.

3. 2. 2 The second regular coded dot matrix pattern (Pattern II)

Ricoh, Nashuatec, Gestetner, Savin, Rex Rotary, and Xante were the objective brands for this category. Their color laser printouts exhibited the characteristics of the prototype of this class. The prototype of this class has certain specific features that can be summarized as follows:

i. All printed coded dot matrix patterns were grouped horizontally and vertically in rows and columns.
ii. Both horizontal rows and vertical columns were composed of the iterated coded dot matrix pattern.
iii. The distances around each iterated coded dot matrix pattern were constant, and there was a space corresponding to another pattern.
iv. Each iterated coded dot matrix pattern was separated from another one (horizontally and vertically) by two sets of two neighboring dots. These sets were located in the upper left corner of each pattern (red color in Fig. 5).
v. Each iterated coded dot matrix pattern had a defined configuration composed vertically of seven columns and eight rows horizontally.

In Fig. 5, all the corporate features of the second regular coded dot matrix pattern of all six brands of color laser printers falling in this category were accurately visualized.

For each brand from this category, the same models possess agreements with the first three rows of the defined pattern.

Moreover, after the fifth row, the distribution of coded dot-matrix inside the iterated pattern is changeable.

Although the identity of the coded dot matrix patterns of Ricoh, Nashuatec, Gestetner, Savin, Rex Rotary, and Xante brands had defined shapes, the uniqueness of each CDMP was different. The serial number and the model of the printing machine were the two features found entirely in CDMP.

The distribution of the coded dot matrix inside the iterated pattern represented the uniqueness of each brand. Any information about the date or the time of printing was not available.

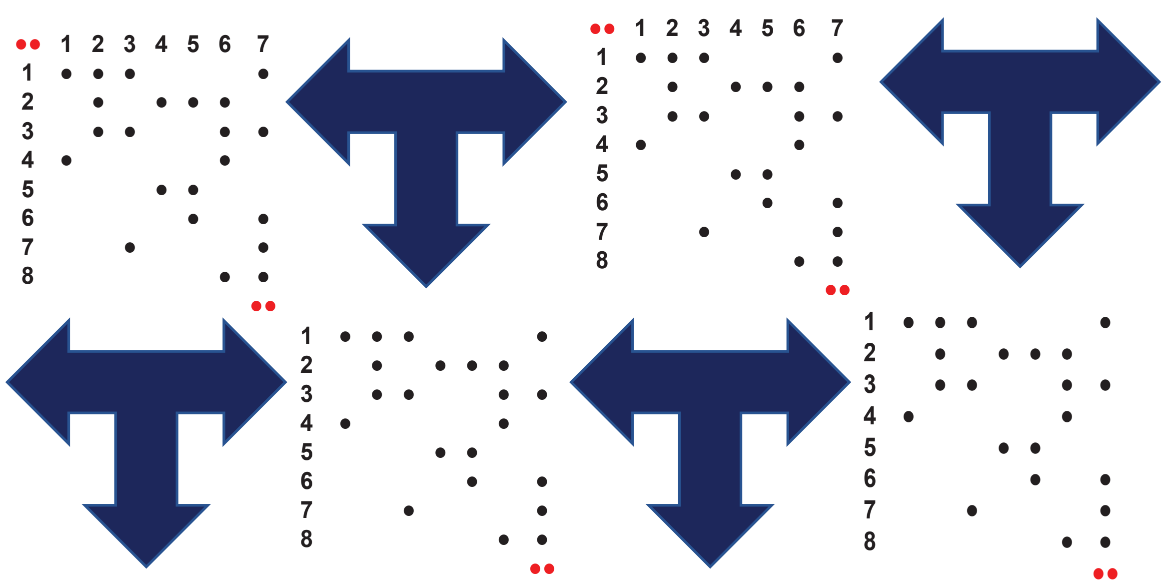

Figure 5- *The simulated form of four repeated coded dot matrix patterns for color laser printout of Ricoh brand.*

The third regular coded dot matrix pattern (Pattern III)

Xerox, Dell, and Epson were the objective brands for this category. Their color laser printouts exhibited the prototype characteristics of the Pattern III class.

The prototype of this class had certain specific features that can be summarized as follows:

i. All printed coded dot matrix patterns were grouped horizontally and vertically in rows and columns.

ii. Both horizontal rows and vertical columns were composed of the iterated coded dot matrix pattern.

iii. The distances around each iterated coded dot matrix pattern were constant and there was a space corresponding to another pattern.

iv. Each iterated coded dot matrix pattern was separated from another one (horizontally and vertically) by constant distance (see Fig. 6).

v. Each iterated coded dot matrix pattern had a defined configuration composed vertically of fifteen columns and eight rows horizontally.

In Fig. 6, all the corporate features for all six brands of the third regular coded dot matrix pattern were visualized accurately.

By deep exploration of this pattern, the discrimination of three regions is represented: time, date, and serial number. The regions of time and date were changed by intervals at the time of the sampling. The region of the serial number occupied columns [11-14]. This region was unique for each encountered color printing machine falling under this category.

The date and time features are only presented in multifunction and large printing machines. All small-color office laser machines do not possess this option. That is why their position in the pattern was still empty in columns 2, 6,7, and 8, Fig. 6. The differentiation of the identity between variant brands

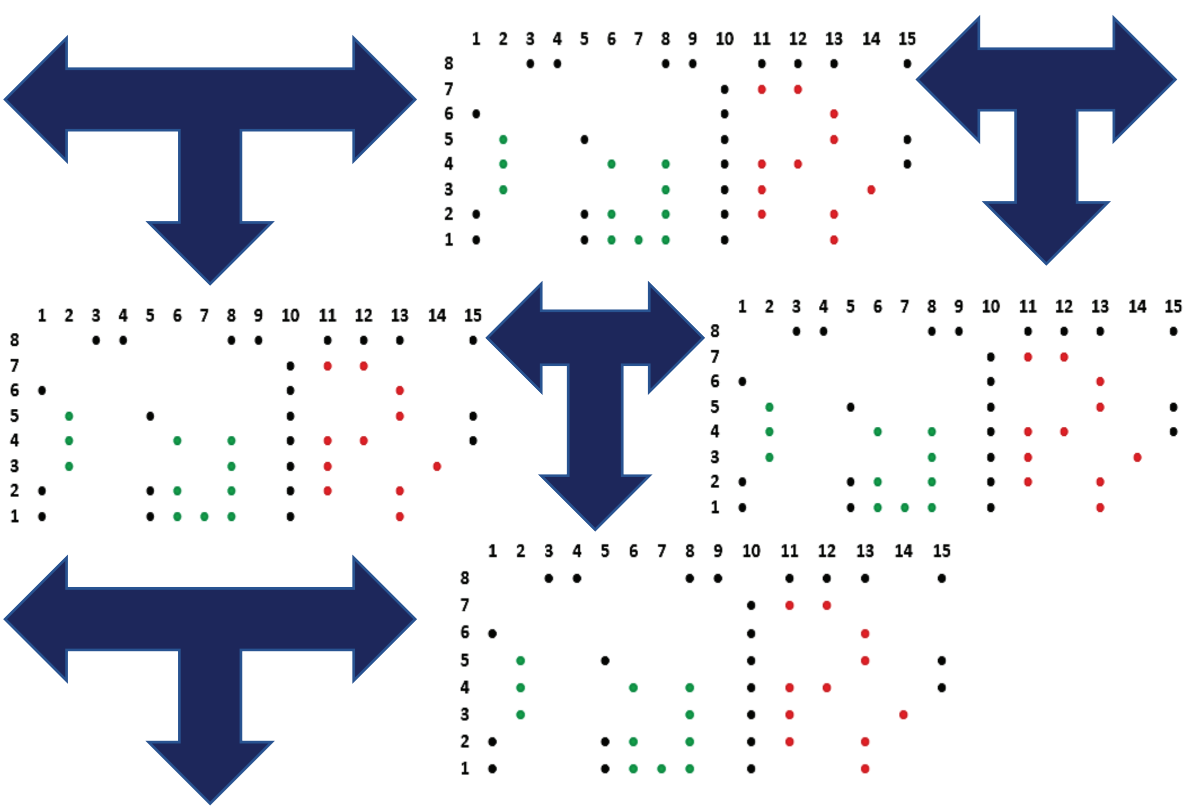

Figure 6- *The simulated form of four repeated coded dot matrix patterns for color laser printout of Xerox brand.*

is figured out in columns 3 and 4 for each brand of this category.

These regions are typically applied for all prints investigated in this work. But these regions may be atypically for other models of the Xerox brand that are not included in the current work.

3. 2. 3 The fourth regular coded dot matrix pattern (Pattern IV)

Lexmark brand was the unique coded dot matrix pattern of this class. The color laser printouts exhibited the catachrestic prototype for Pattern IV.

The prototype of this category has specific features that can be summarized as follows:

i. All printed coded dot matrix patterns were grouped horizontally and vertically in rows and columns.

ii. Both horizontal rows and vertical columns were composed of the iterated coded dot matrix pattern.

iii. The distances around each iterated coded dot matrix pattern were constant and there was no space corresponding to another pattern.

iv. Each iterated coded dot matrix pattern was separated from another one (horizontally and vertically) by two sets of three upright dots. And these sets were located on the upper corners of each pattern.

v. Each iterated coded dot matrix pattern had a defined configuration composed vertically of six columns and nineteen rows horizontally.

vi. The distribution of coded dots from row number one to six of each iterated coded dot matrix pattern was constant.

vii. There was no change in the distribution of each iterated coded dot matrix pattern of any

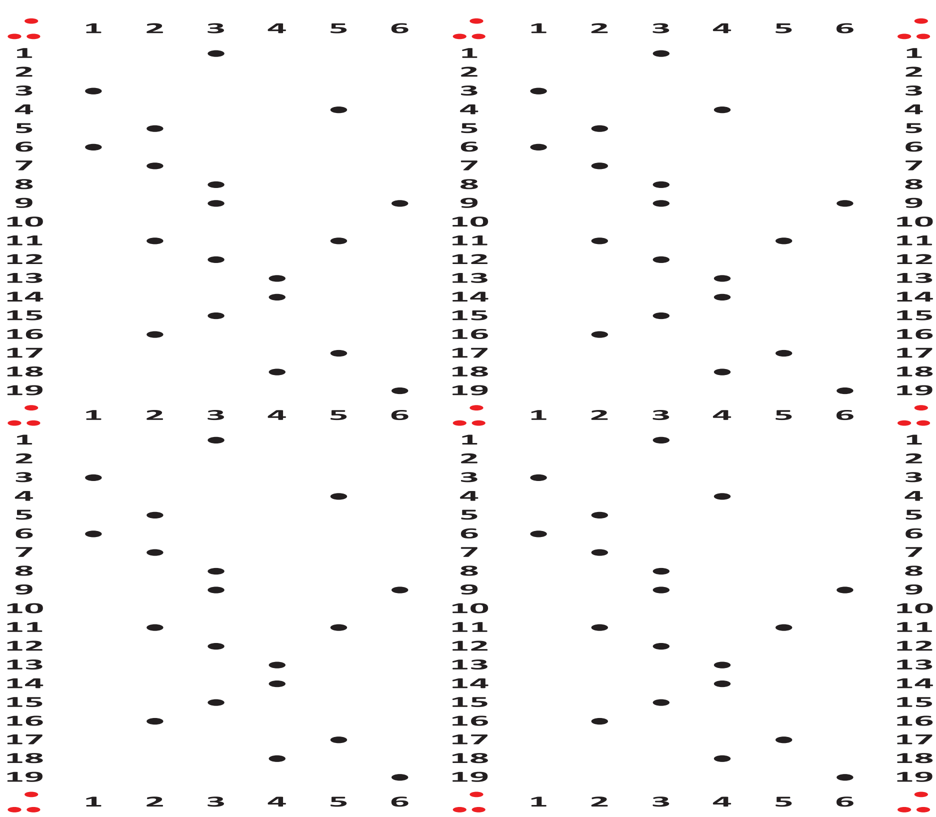

Figure 7- *The simulated form of four repeated coded dot matrix patterns for color laser printout of Lexmark brand.*

prints by printing at different times from the original ones for each sampled printing machine.

In Fig. 7, the corporate features of this brand for the fourth regular coded dot matrix pattern were visualized accurately.

From Fig. 7, the simulated pattern with marked red color for the two sets of three upright dots located on the upper corners of each pattern.

Furthermore, the Lexmark brand was characterized by discrimination of its columns and rows that determined its identity and uniqueness among the previous patterns I, II, and III.

Moreover, the uniqueness of each color laser printer could determine by comparing the distribution of coded dots inside the defined configuration below the sixth row, hence all samples of this brand contained the same constant distribution of their coded dots at the first six rows.

3. 2. 4 The fifth regular coded dot matrix pattern (Pattern V)

The Sharp brand was another one that exhibited the unique coded dot matrix pattern of this class and its color laser printouts presented a new prototype for this pattern.

The prototype of this category has specific features that can be summarized as follows:

i. All printed coded dot matrix patterns were grouped horizontally and vertically in rows and columns.
ii. Both horizontal rows and vertical columns were composed of the iterated coded dot matrix pattern.
iii. The distances around each iterated coded dot matrix pattern were constant and there was space corresponding to another pattern.
iv. Each iterated coded dot matrix pattern was separated from another one (horizontally and vertically) by constant distances.
v. Each iterated coded dot matrix pattern had a defined configuration composed vertically of eleven columns and ten rows horizontally.
vi. The distribution of coded dots for each iterated coded dot matrix pattern was inconsistent.
vii. There was no change in the distribution of each

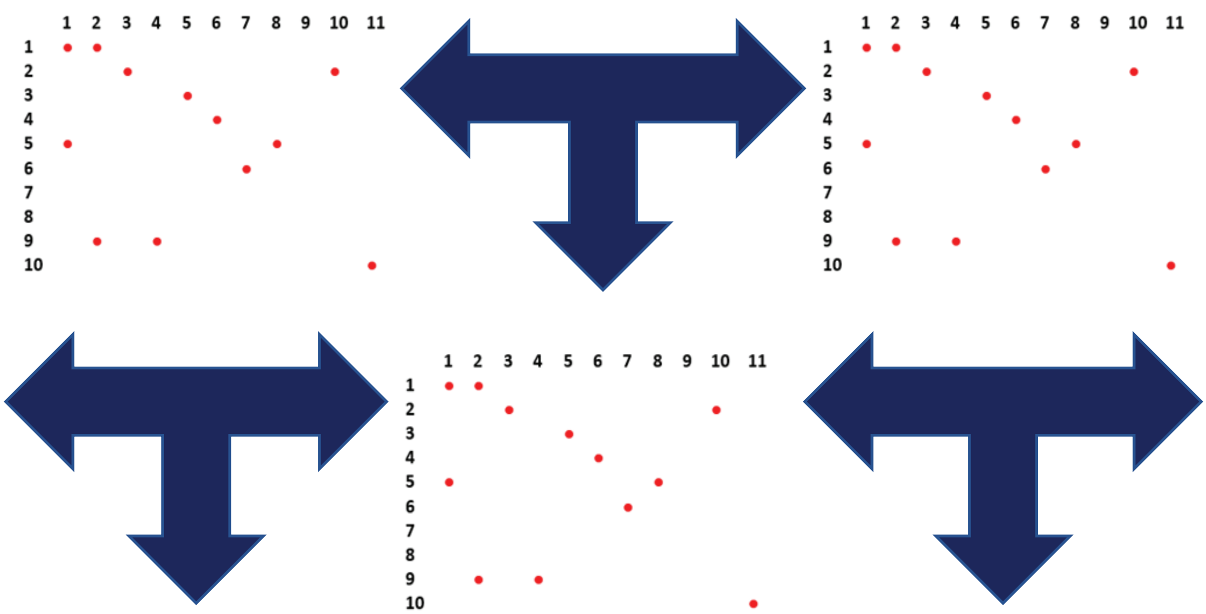

Figure 8- *The simulated form of three repeated coded dot matrix patterns for color laser printout of Sharp brand.*

iterated coded dot matrix pattern of any prints by printing at different times from the original ones for each candidate printing machine.

In Fig. 8, the corporate features of this brand for the fifth regular coded dot matrix pattern are visualized accurately.

As seen in Fig. 8, all red-coded dots of the Sharp brand were characterized by their identity. And the distribution of coded dots inside the matrix pattern was different from one to another of the same brand that achieved the unique characterization.

3. 3 The irregular category

In the irregular category, investigated brands were classified into two well-discriminated coded dot matrix patterns: Canon, and Konica Minolta.

The characterizations of these classes were different than the regular ones. In this category, coded dot matrix pattern shapes were entirely irregular in their uniform. And, their configurations were inconstant, and their distributions inside their matrix were also inconstant. Therefore, their determination was a difficult mission.

Therefore, each class will illustrate as presented in the following scenarios.

3. 3. 1 The first irregularly coded dot matrix pattern (Pattern VI)

The coded dot matrix patterns of the Canon brand were the first class of the irregular category. Herein, we could not speak about columns or rows, therefore, we discussed only the coded pattern shape.

In Fig. 9, the captured live image of the color laser printout is presented. As can be seen that all coded dots spanned onto the entire printouts in diagonal lines to exhibit a wavy or rainy form. Red circles represented the neighboring oblique two dots that surrounded each iterated coded dot matrix by two sets. Furthermore, each iterated coded dot matrix pattern was grouped inside the parallelogram rectangle.

The coded dot-matrix distributions inside corresponding rectangle patterns differed from the printouts of the different models. There was no changeability of the coded dot-matrix distribution inside the same printouts when printing at interval times. So,

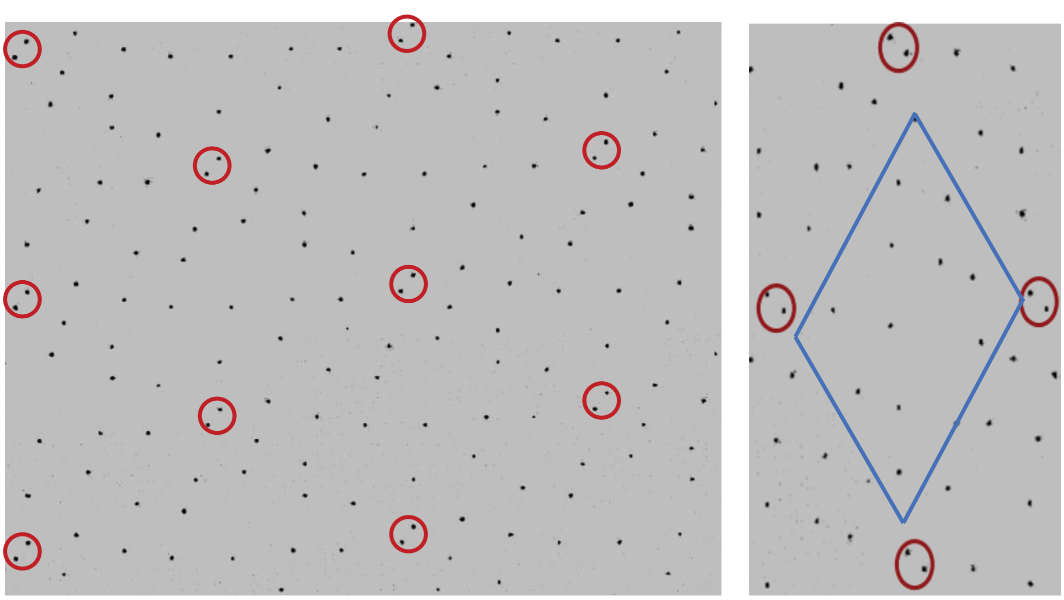

Figure 9- *A live image of irregular coded dot matrix pattern exhibiting shape, configuration, and distribution of Canon sample under hyperspectral imaging (left repeated patterns, and right only one repeated matrix pattern).*

any information about the date or the time of the printing process was not present.

3. 3. 2 The second irregularly coded dot matrix pattern (pattern VII)

The color laser printers of the Konica Minolta brand were categorized into the second class of irregularly coded dot matrix patterns. Since there are no definite regular coded patterns in this type of pattern, therefore we could only speak about the overall shape of the pattern.

Fig. 10 shows the captured live image of a color laser printout produced by Konica Minolta laser printers. As can be seen in Fig. 10 that the coded dot matrix pattern spread in a random mode onto the entire paper sheet prints. The main characteristic of this class of pattern is based on the set of separation dots marked by oval shapes. Blue boxes were drawn to identify the iterated coded dot matrix pattern of this class.

Each iterated coded dot matrix pattern, was surrounded by four sets of three upright dots, which separated them vertically and horizontally, respectively.

Again, there is no difference in the distribution of coded dot-matrix inside rectangle patterns after printing at different times of the corresponding original ones.

These outcomes of date, and time, are typically applied for all prints investigated in this work.

But, different outcomes of the date and the time of the printing process may be atypical of other models of the Konica Minolta brand that have not been included in the current work.

To sum up, experimental results summarize and introduce the new novel scheme depicted in Fig. 11.

4. Conclusions

In the present study, nineteen different brands of color laser printing machines being used globally presented around the world were explored. One thousand three hundred forty-three color laser printouts were investigated with a non-destructive technique directly by the video spectral comparator Regula® 4307 using hyperspectral analysis mode.

All color laser printout specimens of this study had tracking dots in different shapes, configurations, and distributions. All brands of color laser printers were successfully tracked and identified based on

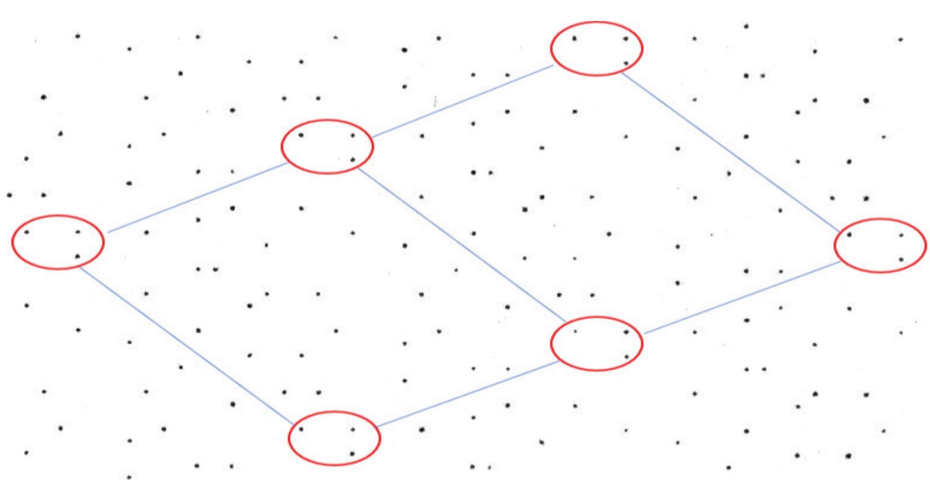

Figure 10- *A live image of irregular coded dot matrix pattern exhibiting shape, configuration, and distribution of Konica Minolta sample under hyperspectral imaging.*

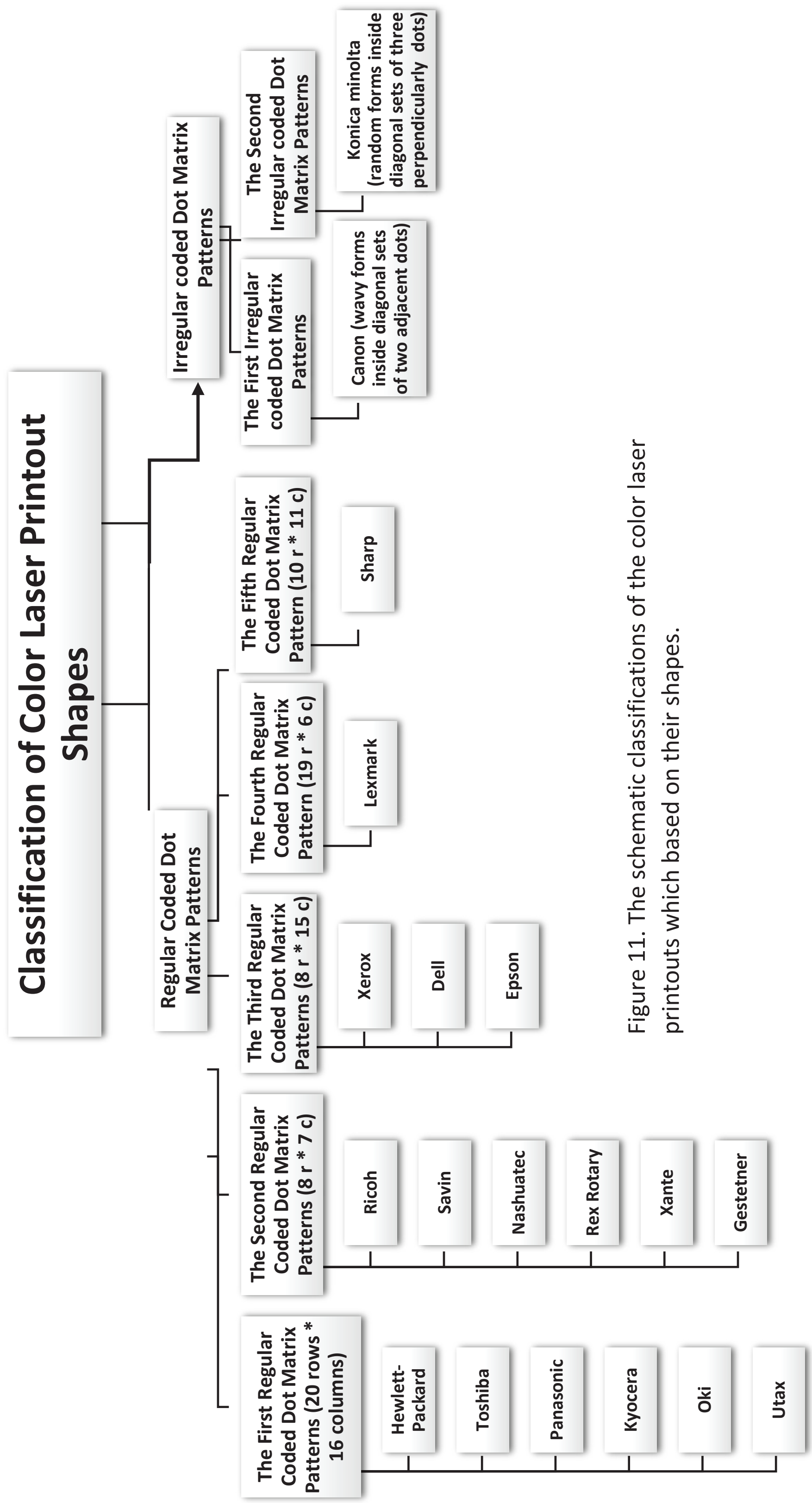

Figure 11- *The schematic classifications of the color laser printouts which based on their shapes.*

the coded dot matrix patterns using VSC Regula® 4307 and hyperspectral analysis mode.

All coded dot matrix patterns of nineteen different brands of color laser printers were segregated and classified into two broad categories according to the regularity of their shapes using the class and individual characteristics altogether. The regular category could be further grouped into five different coded dot matrix patterns. These patterns were identified based on regularity in shapes, well-defined configurations, and variant distribution of coded dots inside their CDMP.

The irregular category breaks down into two different models of coded dot matrices. These models were characterized by their irregular shapes, inconsistent configurations, and variant distribution of coded dots inside their CDMP.

A novel schematic classification of the color laser printouts based on their shape formality was presented. This new classification facilitates the discrimination between one or more variant color laser printouts in a forensic document examination lab swiftly and individually utilizing direct technique with a precise route of hyperspectral analysis with a conclusive accuracy percentage.

Conflict of interest

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