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Determination of Relative Age of Inkjet and Laser Printouts by CIE L*a*b* Color Space

Dr. Kapil Kumar[a*], Dr. Shobhana Menon[b]

[a,b]*Department of Forensic Science, Gujarat University, Ahmedabad, India*
[a]*Email: kkforensic@gmail.com*

Abstract

Questioned documents are sometimes made to look old in order to make them appear genuine and age of a document should be promptly investigated in every possible manner. In this paper, a reliable, simple and effective method for determination of relative age of inkjet and laser printouts, kept in three different environmental conditions over a period of month time is reported. For this, their chromaticity values obtained from the absorbance and UV fluorescence spectra and the change in colour difference denoted as ΔE*ab gave a significant correlation coefficient over time. The data obtained also illustrates possible chronological aging of printed text and ultimately explaining drying process. This enabled not only to analyse the studied material in a non-destructive manner but also to study the breakdown of colour and pigment present in toner/ink under different environmental conditions and in this way increases the possibility to distinguish them on account of time of printing.

***Key words*:** Forensic Science; Questioned Document; age of document; printers.

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* Corresponding author.

1. Introduction

Massive use of digital printers and photocopier machines in offices, companies and private properties, because of their affordable price and copies similar to the original documents, has increased the problem of forgery relating to them. Forgeries due to printers includes addition and substitution of text, making counterfeit copies of original and sometimes documents altered by inserting new lines or contents. Dating of printed text is important in cases in the context of re-entries in medical or legal, made in short or long duration, after the dates recorded in the file. In some circumstances it becomes important to answer whether the entire document or part of it is printed simultaneously at one go or part of it inserted afterwards, this concept of relative age of document is also important in cases, irrespective of the actual time of printing. Ultimately it determines variation in the time of printing. Environmental factors effecting on inks/toners on paper make it one of the most difficult and hardest problems to solve in forensic science.

Several methods are addressed for such queries and analysis are performed by either comparing questioned document with the standard[1]. Apart from non-analytical techniques [2-4] many analytical techniques are employed to discriminate printers. Even trash marks, printing voids and streaks can have dating significance. Age determination based on availability of the copying or printing process at disputed documents date restrict to printing technology and to a particular year but in cases where the printing technology dates the dispute documents date and questioned and standard printouts are contemporary, it becomes insignificant.

Document forensics technology, mostly focuses on determining the source of a document or on detecting forgery, has developed rapidly in recent years. This technology uses commodity scanners and a computer to perform the necessary analyses. The analyses can be automatic or semi-automatic, reducing costs while increasing convenience [14-23].

Many separation methods have been previously suggested by researchers to determine age of writing ink [7-11]. Michelle and his colleagues in 2009 used CIE color space to measure hair color by reflectance spectrophotometer and DIA (12). In aging process, ink/toner on paper that is in open system undergoes color changes due to environmental and other factors effecting on it. To understand the changes, one must first have the knowledge of color perceptions as visible by human eyes. There are other less frequent technologies such as dye-sublimation printers and inkless printers. However, most of the research has been focused on the two earlier technologies, as toner-based and inkjet printers are the most employed [5]. Visual perception of color can be expressed in numbers by many different systems which have been developed from time to time. Colorimetry can be used to measure the color of ink or toner from paper surface whereas chromaticity scale is widely used in forensic analysis of different exhibits like hair color, post mortem changes (lividity) [24], age of bruises etc. [25]. Use of chromaticity scales in forensic science has been started after middle eighties.

Chromaticity coordinates provides a numerical measure of a color and determined from suitable type of spectral graphs. It also allows to be represented by a point on the appropriate chromaticity diagram. Different coloring and measuring systems have been reported from time to time like XYZ, xy, uv, RGB (Red, Green, Blue) and L*a*b* by Commission International de l'Eclairage (CIE). CIE L*a*b* system is one of the most promising and modern system for mathematical color representation and finds wide application in forensic science specially in forensic medicine, color related studies and aging processes. However, no study has been reported on the application of CIE L*a*b* for document examination specially to determine age of inkjet and laser printed documents.

In CIE L*a*b* system, the L* value defines the relative luminosity of the sample. The value of L* ranges from total black (L* = 0) to total white (L*=100). The a* value gives red-green coordination (-a* defines the color quality as green and +a as red) and the b* value gives blue-yellow coordination, -b* defines the color quality as blue and +b* as yellow) [26]. For the purpose of this study, the chromaticity has been used to evaluate toner/ink color with increasing time in a dynamic state.

2. Materials and method

2.1 Sample preparation

For this study, Five inkjet and five laser printers of varying manufactures are considered for examination purpose (Table-1). While collecting samples, care is taken to note that all the selected printers are refilled with ink from suppliers only and not other than the printer manufacturer. As for the studies of printer inks it is important to see that they are cartridge or toner original and not replaced by less expensive cartridges containing different chemical compositions than original model.

Table 1: Details of printers, manufacturing company and model

Code	Manufacturing Company and Model	Printer code
S1	Brother MFL-J-415	INKJET
S2	HP deskjet ink advance K109	INKJET
S3	Canon LBP 3300	LASER
S4	Konica bizhub C-220	LASER
S5	HP laser M-1009	LASER
S6	Wipro 300	DOT MATRIX
S7	HP deskjet 6940	INKJET
S8	Brother DCP- J- 125	INKJET
S9	Samsung ML 1400	LASER
S10	HP deskjet 3745	INKJET

Dot matrix printers are not much popular and becoming an obsolete technology, but then also one printer in included in study for comparison purpose with printers in study. Six dots (appox.5 mm thick) of black color were printed on plain white A4 size, 75gsm, matrix paper on same day. Each printed sheet was cut into three equal parts. To know the environmental effect samples kept in three different conditions, inside room without any direct sunlight, at any point of time, falling on papers where temperature ranges from 28^0C – 31^0C (referred further as 'naturally' aged sample), second stored at place with no direct sunlight, relative humidity 83% to 87%, temperature ranges 21^0C – 25^0C (referred further as 'moist' aged sample) and the third one exposed to direct sunlight for a time span of 8 hr every day where temperature range is 34^0C – 41^0C (sunlight). This entire study was carried out over a period of 28 days.

2.2 Data Acquisition through spectroscopic Analysis

Chromaticity values measurements as determined by CIE L*a*b* in 1976 were recorded using calibrated video spectral comparator (VSC) 6000/HS (Foster and Freeman, UK) and total energy illuminant and 2 degree observer as reference. The paper's non printed portion is taken as a white reference to measure the absorbance, to influence of paper color on measured values. To avoid diurnal variations if any in ink examination, readings were recorded at a fixed time of the day. Calibrations and measurements were performed under similar conditions. All the absorbance spectra of the prints were obtained over the range 400-1000 nm. All measurements were taken from the central region of the printed dots. Chromaticity values L* (luminosity), a* and b* were determined from absorbance and UV fluorescence spectra in natural and in artificially aging (moist and sunlight) environmental conditions. The correlation coefficient and logarithmic regression between time in days and chromaticity values were carried out using SPSS 22.0 Inc. Logarithmically transforming variables in a regression model is used where a non-linear relationship exists between the independent and dependent variables.

2.3. Parameters used for Analysis

- Incandescent light source (Absorbance) – 400-1000 nm (visible + IR)
- UV fluorescence light source (fluorescence) – 200 to 800 nm

CIE Lab color space were used for relative color parameter differences across a 28 days' time in printed documents under aforesaid three contrasting environmental conditions to know relative age of printed document. The color difference between the day one and subsequent days was calculated. ΔL*, Δa* and Δb* are the difference between each value of L*a*b* color space, day one and increasing weeks' time. The size of color differences is determined by [5] $\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ which indicates the size of color differences. L* value defines the relative luminosity of the sample, a good correlation exist between change in L* and time. Change in L* luminosity of the printed text with time is determined to know the fading effect of toners in open system.

3. Results and discussion

Although, changes occur in the optical and physical properties of the printed strokes on paper surface with time it is not visible to naked eye. The chromaticity scales determine changes in color properties which are beyond perception of eyes. The entire sampling and their results for all 10 printers are divided into the following classes:

3.1 Correlation Studies

A correlation refers to a relationship between two variables. The linear correlation coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson. Correlations can be strong or weak, as well as positive or negative. In other cases, there might be no correlation at all between the variables of interest. The value of correlation coefficient is such that $-1 < r < +1$ where, the + and – signs are used for positive linear correlations and negative linear correlations, respectively.

Here in present study correlation coefficient measures the strength and the direction of a linear relationship between chromaticity values as one variable and other variable of time duration in days. The results are summarized as follows:-

- Correlation coefficient of L* values with increasing time (in days) in the absorbance and fluorescence spectra, in all three environmental conditions are tabulated in Table - 2. The L* value of most of the samples in different environmental conditions showed negative correlation, maximum number of samples in absorbance moist condition. But few samples showed positive and significant correlation with time. In absorbance spectra printer number S1, S2, S6 and S8 correlation coefficient greater than 0.86 is observed under sunlight conditions which is quite a good score. And in fluorescence spectra only three printer's S1, S4 and S8 showed positive correlation with time. From the correlation coefficient statistics we can say that a mixed correlation exist in L* with time, positive and negative correlation exist in different samples and same samples in different environment also. So it can be said that L* chromaticity values alone do not show significant relation with aging samples.
- Correlation coefficient of a* values with increasing time (in days) in the absorbance and fluorescence spectra, in all three environmental conditions are tabulated in Table - 3. Maximum negative values are observed in almost all printers in different environment conditions indicating a reverse correlation between a* value and time i.e. a* value decreases with time. A positive values of chromaticity variable a* indicates red color and moving towards negative indicates green. This clearly indicates that in both type of printers laser and inkjet, the color of the inks/toners, as the time passes shifts to green tint.
- Correlation coefficient of b* values with increasing time (in days) in the absorbance and fluorescence spectra, in all three environmental conditions are tabulated in Table - 4. In chromaticity variable b* many of the values of b* from absorption spectra gave a negative correlation with time, whereas, values of b* from fluorescence spectra gave a significant and positive correlations with time. The b* values from fluorescence samples aged in sunlight gave best results and good correlation indicating importance of b* and fluorescence spectral analysis for age determination. More the value of b* in the fluorescence spectra larger will be the time passed from printing. The b* value will best serve if the time gap between printing of one sample and the other is more.
- Correlation coefficient of ΔE*ab values with increasing time (in days) in (a) absorbance, and (b) fluorescence spectra, in all three environmental conditions are tabulated in Table - 5. A significant positive correlation was obtained in all the conditions in both absorbance and fluorescence spectra. Correlation coefficient above 0.75 is obtained in sunlight aging in most of the cases of both spectra. As ΔE*ab indicates the

size of color difference and includes both the other variables within it, from correlation coefficient data it is evident that it is the most significant, reliable and consistent parameter to be considered for relative age determination. This indicates that greater the value of ΔE*ab calculated of the sample, larger its time of printing in relative study.

Table 2: Correlation coefficient of L* values with increasing time in the absorbance and fluorescence spectra in all three environmental conditions.

	absorbance Spectra			**fluorescence spectra**		
Printers	**Natural**	**Moist**	**Sunlight**	**Natural**	**Moist**	**Sunlight**
S1	-0.7426	-0.34003	0.910065	-0.11062	0.075933	0.877119
S2	0.287556	0.097778	0.8671	0.360827	0.343707	-0.92775
S3	0.064627	-0.44709	0.26282	-0.48843	0.328359	0.645432
S4	0.07301	-0.70985	-0.03941	0.719732	0.633873	0.717139
S5	0.344988	0.597811	0.155561	0.501033	0.29299	-0.85671
S6	0.288584	0.905622	0.873389	0.142723	0.713386	0.693437
S7	-0.92875	-0.01986	-0.94528	0.223352	-0.29223	-0.52422
S8	-0.11095	0.142234	0.965357	-0.50649	-0.65573	0.873934
S9	-0.7404	-0.02219	-0.07901	0.621999	0.964921	0.676051
S10	-0.03961	-0.67666	-0.07752	-0.51387	-0.84589	-0.6058

Table 3: Correlation coefficient of a* values with increasing time in the absorbance and fluorescence spectra in all three environmental conditions.

	Absorbance Spectra			**Fluorescence spectra**		
Printers	**Normal a**	**Moist**	**Sunlight**	**Normal**	**Moist**	**Sunlight**
S1	**0.295735**	**0.724946**	**0.89477**	**-0.11599**	**-0.31195**	**-0.60324**
S2	**-0.92332**	**0.165578**	**0.014816**	**-0.88497**	**-0.69799**	**-0.62565**
S3	**-0.96875**	**-0.08638**	**-0.22679**	**0.442697**	**-0.36255**	**-0.30987**
S4	**-0.85628**	**-0.50461**	**-0.68882**	**-0.73094**	**-0.62747**	**-0.72932**
S5	**-0.37388**	**-0.06519**	**0.337942**	**0.186325**	**-0.71064**	**0.567543**
S6	**0.013086**	**-0.3489**	**-0.52279**	**0.453857**	**-0.53006**	**-0.71322**
S7	**0.27687**	**-0.38529**	**0.538574**	**-0.38749**	**0.425362**	**-0.16508**
S8	**0.137256**	**0.444349**	**0.573049**	**0.528986**	**0.515347**	**-0.65078**
S9	**0.787894**	**-0.00282**	**0.742495**	**-0.67483**	**-0.9817**	**-0.84571**
S10	**0.048103**	**0.936273**	**0.805283**	**0.037462**	**-0.37708**	**-0.63452**

Table 4: Correlation coefficient of b* values with increasing time in the absorbance and fluorescence spectra obtained from samples kept in natural, moist and sunlight conditions.

	absorbance Spectra			fluorescence spectra		
Printers	**Normal**	**Moist**	**Sunlight**	**Normal**	**Moist**	**Sunlight**
S1	-0.33709	-0.57349	0.899049	-0.27247	0.108103	0.923375
S2	0.805318	-0.13842	-0.63773	0.474339	0.929269	0.989684
S3	0.848743	0.545275	0.572747	-0.37973	0.554848	0.757406
S4	0.842422	0.64599	-0.13829	0.728256	0.621918	0.860555
S5	0.01813	-0.27134	-0.79111	0.465626	0.599119	0.662048
S6	-0.20683	0.404421	0.493493	-0.37526	0.658266	0.801761
S7	-0.92615	-0.17521	-0.83305	0.813282	0.213544	0.963266
S8	-0.3651	-0.49462	0.806487	-0.45253	-0.7276	0.94865
S9	-0.72249	-0.04234	-0.77776	0.753431	0.9468	0.97464
S10	-0.0036	-0.78724	-0.86024	-0.14909	-0.70963	0.956476

Table5: Correlation coefficient of ΔE*ab values with increasing time in the absorbance and fluorescence spectra in all three environmental conditions.

	absorbance Spectra			fluorescence spectra		
Printers	**Normal**	**Moist**	**Sunlight**	**Normal**	**Moist**	**Sunlight**
S1	0.650997	0.714026	0.918484	0.347269	0.315181	0.811172
S2	0.590643	0.041634	0.88558	0.278564	0.761878	0.987071
S3	0.829203	0.815655	0.574059	0.669358	0.14997	0.603223
S4	0.827544	0.814418	0.752331	0.087567	0.627996	0.772279
S5	0.395502	0.663077	0.786778	0.674155	0.37538	0.865201
S6	0.215763	0.703187	0.714198	0.478775	0.68636	0.731919
S7	0.964942	0.129365	0.861263	-0.162	0.394169	0.917842
S8	0.429269	0.021695	0.960192	0.626365	0.770642	0.882953
S9	0.773873	0.187557	0.682265	0.419373	0.977264	0.931924
S10	0.033735	0.741558	0.847664	0.347269	0.474896	0.923929

2.3.2 Logarithmic regression

Using the logarithm of one or more variables instead of the unlogged form makes the effective relationship non-linear, while still preserving the linear model. The logarithmic transformations performed transformed a highly skewed variable into one that is more approximately normal. As in correlation data the values of ΔE*ab gave significant relation with time. Logarithmic regressions were estimated for ΔE*ab and represented as logarithmic linear trends.

Table 6: The comparison of significant correlation coefficient values obtained from different printers

Sample code	Printers	Correlation coefficient b* value in fluorescence and time in days in samples artificially aged in sunlight	Correlation of ΔE*ab value in fluorescence samples kept in sunlight and time in days	R^2 value
S1	**Brother inkjet j - 415w**	0.923375	0.811172	0.936
S2	**HP inkjet**	0.989684	0.987071	0.742
S3	**Laser canon lbp**	0.757406	0.603223	0.354
S4	**Laser konica c220**	0.860555	0.772279	0.86
S5	**Hp Laserjet M1005**	0.662048	0.865201	0.852
S6	**Dot matrix wipro**	0.801761	0.731919	0.857
S7	**HP deskjet 6940**	0.963266	0.917842	0.961
S8	**Brother DCP J-125**	0.94865	0.882953	0.975
S9	**Samsung laser**	0.97464	0.931924	0.831
S10	**HP deskjet 3745**	0.956476	0.923929	0.909

Logarithmic linear regression of ΔE*ab in natural, moist and sunlight aging, of absorbance and florescence spectra are given in figure 1 to 6. Linearity was observed in all the graphs, of all brands, data obtained through absorbance and fluorescence spectra under different conditions of the printers. The slope of the laser printer's graph is less as compared to inkjet printers; this may be due to the basic difference in printing process of the both. The regression indicates more stability of laser printers on paper surface than inkjet printers. This may be due to formation of polymer layer on the surface which at the time of printing is heated to make toner permanent on paper. The distribution of chromaticity is moderately skewed, may create a non-linear relationship between chromaticity values and time.

4. Conclusion

Chromaticity measurements L*, a* and b* obtained from absorbance (visible + IR) and florescence (ultra violet) spectroscopy over a period of 28 days to calculate size of color differences (ΔE*ab) were statistical by evaluated and implemented to determine changes in coloring properties of toner and ink (Laser and inkjet) in an open system with increasing time. The statistical results obtained was impressive and indicates correlation between ΔE*ab values and time, as identical in table-5. Out of absorbance and fluorescence spectra studied, chromaticity values of fluorescence spectra gave better correlation with time. In the chromaticity values studied, i.e. L*, a* and b* fluorescence showed better correlation with time, supported by its shift from blue to yellow. Finally, of the various environmental conditions studied, samples artificially aged in sunlight gave best correlation with b* and ΔE*ab. The entire study was carried in three different environmental conditions to study environment effect and drying process. The results obtained also postulated proposed drying procedure of toner and inkjet inks on paper.

The study would be very useful in cases where question is raised on the authenticity of entire printed page inserted afterwards, also in cases like addition, alteration or any kind of changes made by printing from same printer after some laps of time. In such cases, it becomes important to determine relative age of entire printout or some part of it. i.e. whether entire page or part of it is printed simultaneously or at different duration.

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