ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0858 (Print)
ISSN: 2521-0866 (Online)
CODEN: SHJCAS

Science Heritage Journal (GWS)

DOI: http://doi.org/10.26480/gws.01.2023.01.08

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RESEARCH ARTICLE

CROSSING STROKES EXAMINATION FROM CROMATICITY DIAGRAM

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ARTICLE DETAILS

Article History:

Received 23 February 2023
Revised 06 March 2023
Accepted 12 April 2023
Available Online 18 April 2023

ABSTRACT

It is aimed to find exact chronological order in crossing strokes with the help of chromaticity diagram in this experiment. Since, surface on point of intersection corresponds to second stroke in crossing two lines, it is assumed that chromaticity co-ordinate (x,y) of the crossing stroke should be similar to that of second stroke rather than first stroke. We carried out this experiment on crossing strokes made from differernt writing pens and printers. We did experiment many times by preparing different samples each time in both homogeneous and heterogeneous crossing strokes but we get positive and conclusive results only in most of heterogeneous crossing strokes. This work is very helpful to questioned document examiners to examine forgery in document.

KEYWORDS

Crossing Stroke; Video Spectral Comparator; Non-Destructive, Chromaticity

1. INTRODUCTION

Along with the development of technology and printing devices, fraud cases in document is increasing daily like counterfeiting in currency, passport, bank cheque, certificates etc. Forensic document examiners face such problems every day. One of the challenging problem in this feild is to find exact chronological order in crossing strokes (Osborn, 1929). Many equipments and methods like application of Optical Microscope, Scanning Electron Microscope (SEM), pyridine solution and photographic glossy paper, embossed mars left on the back of paper, Electrostatic Deposition Analysis (ESDA), Laser Scanning Confocal Microscopy (LSCM), Raman depth analysis, Raman Spectroscopy, Atomic Force Microscopy (AFM), 3D laser profilometry method, Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS), Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) imaging, Video Spectral Comparator (VSC), Surface-Enhanced Raman Spectroscopy (SERS) etc. are used to find chronological order in crossing strokes (Brito et al., 2017).

Reflection spectra generated by using Video Spectral Comparator-2000HR was used to examine order of sequence in crossing lines and successfully find chronological order in the case of heterogeneous crossing strokes from ballpoint pens whereas they failed in homogeneous crossing strokes and strokes from gel pen (Vaid et al., 2011). Similarly, M. A group researchers used confocal microscope and Docubox Dragon (Mann et al., 2013). Also, other group researhcer also did work for establishing chronological order in crossing strokes of intersecting printed strokes and writing pens with the help of absorption spectra generated by VSC-2000HR (Kaur et al., 2013). They reported inconclusive results and suggested to docunemt examiners not to use absorption spectra generated by VSC-2000HR for determining chronological order of crossing strokes. 3D laser profilometry for determining sequence of homogeneous crossing lines is discussed (Spagnolo 2006). Also, in some study authors described the use of photography with glossy paper treated with Pyridine to lift for establishing chronological order in crossing strokes (Gupta et al., 1987).

Chromaticity diagram and absorption spectra are used for determining chronological order in crossing strokes from pen and printed strokes (Giri et al., 2022). It means nature of crossing is either pen stroke over printed stroke or printed stroke is over pen stroke. Finally it is reported that experiment became successful to determine order of sequence in heterogeneous crossing strokes only if printed stroke is over pen strokes otherwise in other cases negative and inconclusive results were reported. In this work, we choose crossing strokes from pens and printed strokes. It means crossing strokes are either pen versus pen or printed versus printed. This work is also based on concept of chromaticity diagram. We use Video Spectral Comparator (VSC)-6000. Being non-destructive method, it is better to repeat this work by other researchers also in order to establish more authentic and convencing conclusion.

2. THEORY

Retina of human eye consists of two groups of sensors, rods and cones. Human eye vision extends neary between 400 nm to 700 nm. Rods are responsible for luminance whereas cones are responsible for color vision. Cones are divided into short-wavelength sensitive cone (S-cone), middle-wavelength sensitive cone (M-cone) and long-wavelength sensitive cone (L-cone) being responsible for vision of blue, green and red respectively (Bieske et al., 2007). So, human eye converts visible light into three stimuli X, Y and Z : one cone for red (X), one cone for green (Y) and one cone for blue (Z). These three values X, Y and Z are called tristimulus values and represents the amount of red, green and blue needed to form a particular color. Here, relation betwwen RGB and XYZ can be obtained from below mathemetical expression.

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.240 & -1.537 & -0.498 \\ -9.69 & 1.876 & 0.042 \\ 0.056 & -0.204 & 1.057 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (1)$$

Similarlly, mathmetical relation between LMS and XYZ is given by Hunt-Pointer-Estevz (HPE) matrix as

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Cite The Article: Roshan Giri, Shanker Prasad Chimouriya, Bal Ram Ghimire (2023). Crossing Strokes Examination from Cromaticity Diagram. *Science Heritage Journal, 7(1): 01-08.*

$$\begin{pmatrix} L \\ S \\ M \end{pmatrix} = \begin{pmatrix} 0.3897 & 0.6890 & -0.0787 \\ -0.2298 & 1.1834 & 0.0464 \\ 0.0000 & 0.0000 & 1.0000 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (2)$$

These tristimulus values X, Y, Z generate three-dimensional color space which is very complex (Suresh and Jain, 2013). So, these three stimuli should be normalized and normalization is done by following operations.

$$x = X/(X+Y+Z) \quad (3)$$

$$y = Y/(X+Y+Z) \quad (4)$$

$$z = Z/(X+Y+Z) \quad (5)$$

Here, value of 'z' is obtained from 'x' and 'y' by using very simple relation z = 1 – (x +y) since x + y + z = 1. Here, x, y and z are called trichromatic coefficient. Tristimulus values give absolute values whereas trichromatic coefficient gives relative values of red, green and blue to form a specific color (Suresh and Jain, 2013). Hence, by defining trichromatic coefficient, three-dimensional color space is reduced into two-dimensional (x,y) color space.

Every color has its own specific appearance depending upon three elements: hue, chroma and value. Hue simply refers to object's color – red, orange, green, blue etc. Chroma is the vividness or dullness of a color and value or lightness describes luminous intensity of a color i.e. its degree of lightness. Hue and saturation together form chromaticity. So, any color can be specifically characterized its brightness and chromaticity. Chromaticity diagram or CIE chromaticity diagram proposed by Commission International de I'Eclairage is an objective specification of the quality of color (Commission International de I'Eclairage, 1931). It is a graph which shows all possible colors and each color is defined by a pair of numerical co-ordinate – the chromaticity co-ordinate (x,y). If two colors differ in chromaticity, they are represented by two different points in chromaticity diagram (CIE Techn. Report, 2006).

When two lines cross each other, there will be one colored layer over another colored layer. Hence, this work is based on the fundamental assumption that chromaticity co-ordinate (x,y) of crossing stroke must match with that of second stroke rather than first stroke since thin ink layer of second stroke is above the first stroke.

3. MATERIALS AND METHOD

In this experiment, we tried to use most of the pens and printers found in our local market. Finally, we chose 15 different pens including cello maxriter, pilot pen, cello pointec and cello techno tip of different colors like black, red, green and blue. Among them, cello maxriter and cello techno tip pens are ballpoint pens whose ink is generally a paste containg around 25 to 40 percentage of dye suspended in a mixture of solvents like benzenyl alcohol, phenoxyethanol etc and fatty acids. Different types of oils are also used to make paste more smooth. Ink of pilot pen is either oil-based ink or water-based ink. Here, cello pointec pen is gel pen. Ink of such pen is pigments suspended in water-based gel. Printers include Canon LBP 3300, Canon LBP 2900 and EPSON L805. Among them, EPSON L805 printer is color printer and four different color strokes (red, black, green and blue) are developed from this printer. Other remaining two printers are black and white printer from which only black printed strokes are produced. We prepared our samples of crosing strokes on white photocopy and photo papers. In this work, we use Video Spectral Comparator (VSC)-6000 to generate chromaticity co-ordinates and diagrams.

3.1 Video Spectral Comparator (VSC)-6000

Video Spectral Comparator (VSC) is very useful tool in the field of document examination which helps an examiner to analyze ink, reveal alteration in document visualize hidden security features in currency etc., determine chronological of crossing strokes enhance handwriting on charred documents etc. (Manal and Abd, 2014; Panday et al., 2018; Pathak and Paul, 2019; Gupta and Ravi, 2017; Gupta at al., 2016; Vaid et al., 2011; Kaur et al., 2013; Moorthy and Narayanan, 2016). that uses different light sources for examination of document. At first power of VSC is switch on and appropriate setting is done before working. The proper position of document is adjusted by viewing on the monitor and in order to get large sample size, the image is zoomed to maximum. After placing the document in required and proper position, chromaticity diagram is generated from different three points of first, second and crossing strokes. Once the required diagram is obtained, then it is saved. Light of wavelength ranging from 400 nm to 1000 nm is used to develop chromaticity co-ordinates and diagrams. Finally, chromaticity co-ordinates from first, second and crossing strokes are compared by plotting in chromaticity diagram to make final conclusion.

4. RESULTS AND DISCUSSION

We performed our experiment in both homogeneous and heterogeneous crossing strokes. So, on the basis of nature of prepared samples, this section is further divided into two subsections in order to make obtained results more clear.

4.1 Crossing Pen Versus Pen Strokes

Here, cross strokes are prepared from writing pens only i.e. both first and second strokes are only from pens. Also, on the basis of colors of strokes, this section is further devided into homogeneous and heterogeneous.

4.1.1 Homogeneous Crossing Stroke

Homogeneous crossing stroke refers to two crossing lines of same colors. To prepare such homogeneous crossing lines, at first we write straight line and then another line is drawn over first line by using same color pen of another brand like crossing lines from black pilot pen and black cello techno tip pen.

We did our experiment in all homogeneous crossing stroke sample prepared by ballpoint pen, pilot pen having water-based ink and gel pens. Negative and incnclusive results are obtained in all samples i.e. application of chromaticity diagram is not found as an effictive tool to find chronological order in crossing lines of same colors. One of the negative result is discussed in detail where first stroke is made by red pilot pen and over which second stroke is written by red cello techno tip pen crossing each other.

Different chromaticity co-ordinates generated from first stroke of red pilot pen, second stroke of red cello techno tip pen and cross stroke is shown in Table 1 and plot of these different co-orinates in chromaticity diagram in fig 1, fig 2 and fig 3 where +1, +2, +3 represent for first stroke; +4, +5 +6 represent for second stroke and +7, +8, +9 represent for cross stroke. According to these diagrams, even two different strokes (first and second stroke) of same colors are not clearly dintinguishable. They are nearly at same place of diagrams. Also, co-ordinates of crossing strokes do not correspond to that of second stroke. Hence, negative result is reported.

Table 1: Different chromaticity co-ordinates where numbers 1, 2 and 3 for first stroke by red pilot; numbers 4, 5 and 6 for second writing stroke by red cello techno tip pen; numbers 7, 8 and 9 for crossing stroke

Number	X	Y	Z	x	y	u	v	L*	a*	b*	u*	v*
1	0.629	0.416	0.234	0.492	0.325	0.333	0.33	70.6	55.3	26.1	112.1	19.1
2	0.638	0.418	0.219	0.5	0.328	0.337	0.332	70.7	56.6	29.0	116.7	21.7
3	0.629	0.416	0.241	0.489	0.324	0.331	0.329	70.6	55.2	24.8	110.8	18.0
4	0.606	0.423	0.309	0.453	0.316	0.308	0.322	71.1	47.8	14.9	90.1	8.7
5	0.58	0.412	0.268	0.46	0.327	0.307	0.327	70.3	44.9	19.9	88.3	14.9
6	0.589	0.407	0.313	0.45	0.311	0.309	0.32	70.0	48.6	12.4	89.2	5.7
7	0.571	0.389	0.21	0.488	0.332	0.325	0.332	68.7	49.8	27.1	102.0	21.3
8	0.496	0.332	0.199	0.483	0.323	0.326	0.328	64.3	49.6	21.7	96.9	15.3
9	0.643	0.458	0.302	0.458	0.327	0.305	0.326	73.4	46.0	20.0	90.4	15.3

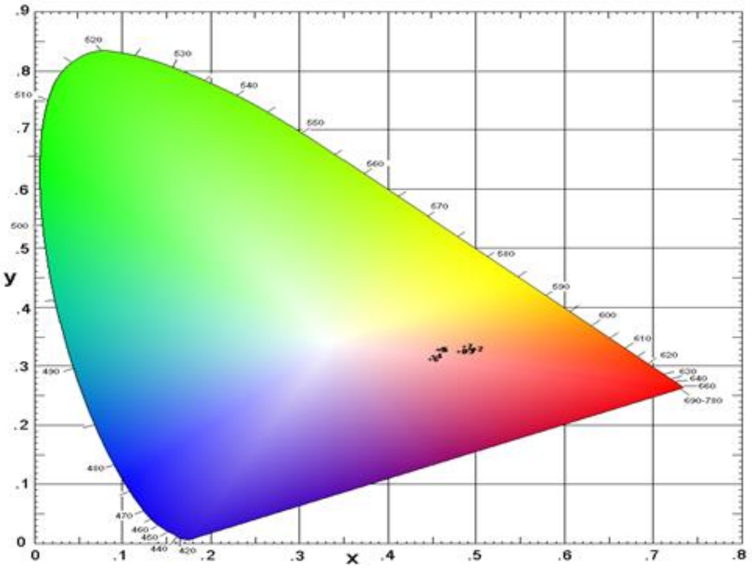

Figure 1: xy Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red pilot pen; +4, +5 and +6 represent for second writing stroke by red cello techno tip pen; +7, +8 and +9 represent for crossing stroke

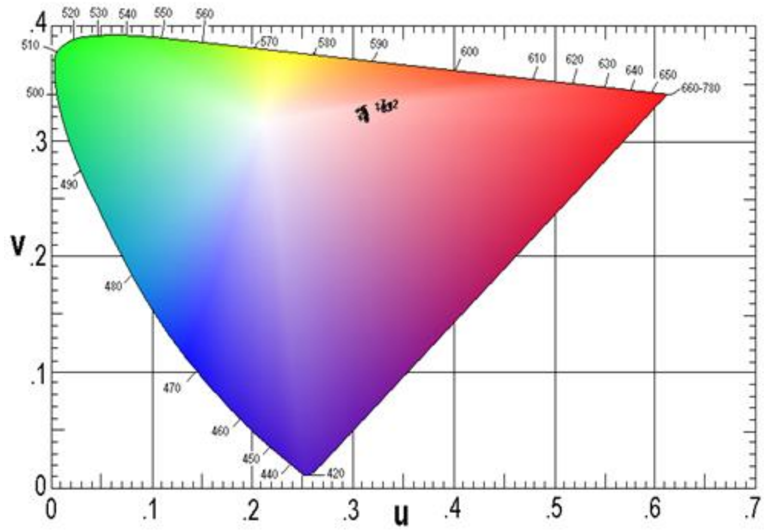

Figure 2: uv Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red pilot pen; +4, +5 and +6 represent for second writing stroke by red cello techno tip pen; +7, +8 and +9 represent for crossing stroke

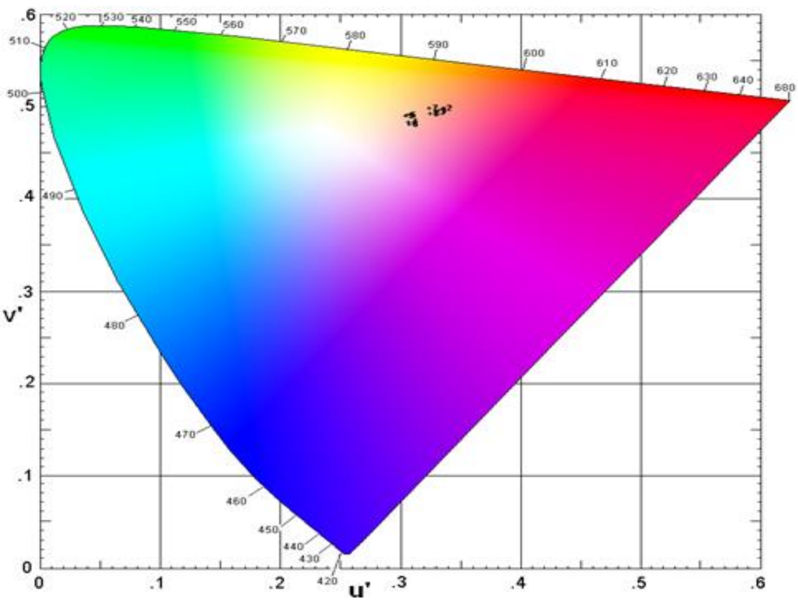

Figure 3: u'v' Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red pilot pen; +4, +5 and +6 represent for second writing stroke by red cello techno tip pen; +7, +8 and +9 represent for crossing stroke

4.1.2 Heterogeneous Crossing Stroke

In this sample of crossing stroke, we use two different colors. It means two writing strokes of different colors intersect each other. We perform the experiment in all samples but we obtain negative results in those heterogeneous crossing strokes involving pilot pen (water-based ink) and cello pointec pen (gel pen) either in the form of first stroke or second stroke. We become able to get positive results only in ballpoint pens (cello techno tip pen and cello maxriter pen). In this section, negative result is not explained in detai but we have discussed about one positive resuly with the help of chromaticity diagram where first stroke is from red cello techno tip pen and over which second stroke is made from black cello maxriter pen.

Different chromaticity co-ordinates generated from first stroke of red cello techno tip pen, second stroke of black cello maxriter pen and cross stroke is shown in Table 2 and plot of these different co-ordintes is shown in Figure 4, Figure 5 and Figure 6. From these diagram, we find that chromaticity of first stroke (+1, +2 and +3) are near to each other whereas that of second stroke (+4, +5 and +6) are in different place. Chromaticity of cross stroke (+7, +8 and +9) clearly correspond with second stroke which is accprding to our assumption. So, we get positive and conclusive result for heterogeneous crossing strokes from ballpoint pen.

Table 2: Different chromaticity co-ordinates where numbers 1, 2 and 3 for first stroke by red cello techno tip pen; numbers 4, 5 and 6 for second writing stroke by black cello maxriter pen; numbers 7, 8 and 9 for crossing stroke

Number	X	Y	Z	x	y	u	v	L*	a*	b*	u*	v*
1	0.75	0.599	0.402	0.428	0.342	0.274	0.329	81.8	32.8	21.0	67.7	20.3
2	0.658	0.496	0.368	0.432	0.326	0.286	0.323	75.8	39.1	15.1	74.5	11.4
3	0.876	0.726	0.513	0.414	0.343	0.263	0.327	88.3	29.0	19.6	60.6	19.9
4	0.149	0.132	0.158	0.34	0.3	0.23	0.304	43.1	10.5	-6.3	10.7	-9.9
5	0.382	0.348	0.447	0.324	0.296	0.22	0.301	65.6	11.1	-12.2	7.9	-19.9
6	0.294	0.268	0.333	0.329	0.299	0.222	0.303	58.8	10.1	-9.7	8.6	-15.1
7	0.164	0.135	0.155	0.362	0.297	0.248	0.305	43.5	17.2	-4.8	21.0	-8.9
8	0.193	0.171	0.221	0.33	0.292	0.226	0.3	48.4	11.4	-9.9	9.5	-15.1
9	0.156	0.131	0.164	0.346	0.29	0.239	0.301	42.9	15.4	-8.1	15.9	-12.8

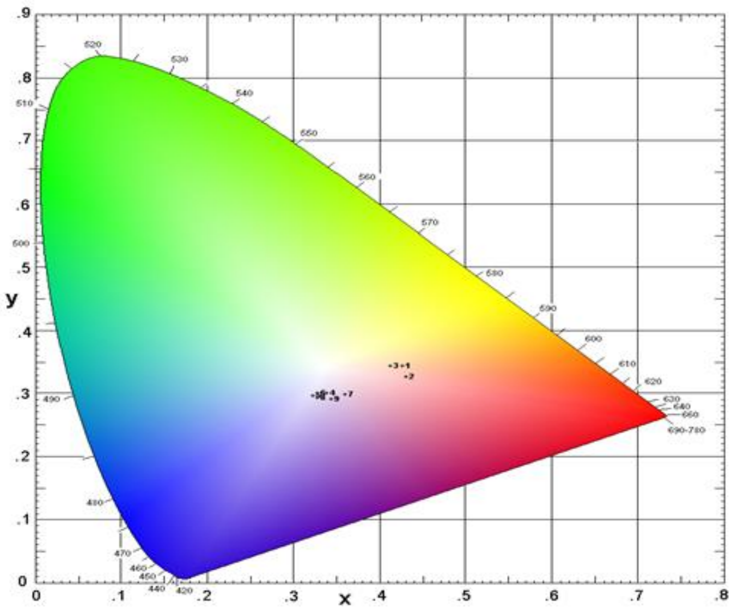

Figure 4: xy Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red cello techno tip pen; +4, +5 and +6 represent for second writing stroke by black cello maxriter pen; +7, +8 and +9 represent for crossing stroke

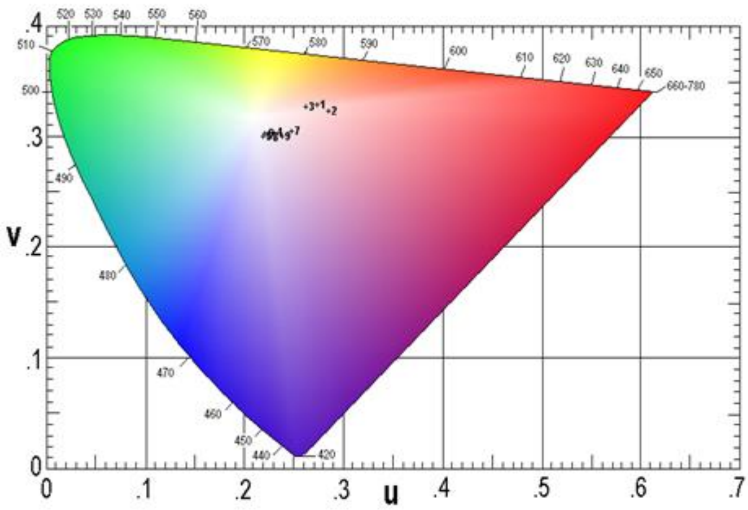

Figure 5: uv Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red cello techno tip pen; +4, +5 and +6 represent for second writing stroke by black cello maxriter pen; +7, +8 and +9 represent for crossing stroke

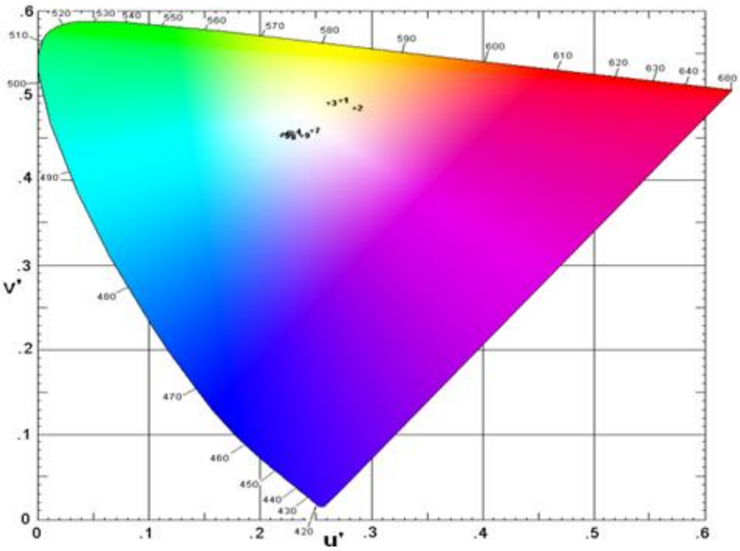

Figure 6: u'v' Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first stroke by red cello techno tip pen; +4, +5 and +6 represent for second writing stroke by black cello maxriter pen; +7, +8 and +9 represent for crossing stroke

4.2 Crossing Printed Versus Printed Strokes

Similarly, in this part, cross strokes are prepared from printers only i.e. both first and second strokes are only from printes. This section is also further devided on the basis of colors into homogeneous and heterogeneous.

4.2.1 Homogeneous Crossing Strokes

When two lines of same colors cross each other, crossing stroke is said to be homogeneous. We prepared such types of cross strokes from the same and different printers and perform experiment in all samples. We found totally negative results in all samples i.e. result is against our assumption. Here, we have explained one of the negative results in detail where first black printed stroke is from Canon LBP 2900 printer and second black printed stroke is from Canon LBP 3300 printer. Different chromaticity co-ordinates for this sample is represented in Table 3 and its plot in chromaticity diagram is presented in Figure 7, Figure 8 and Figure 9. From different chromaticity diagram (Figure 7, Figure 8 and Figure 9), it is even difficult to differentiate first and second stroke because all points are grouped and clustered at nearly same place of diagram which is totally against our fundamental assumption. So, application of chromaticity diagram to find chronological in homogeneous printed crossing stroke is totally failed.

Table 3: ***Different chromaticity co-ordinates where numbers 1, 2 and 3 for first black printed stroke by Canon LBP 2900 printer; numbers 4, 5 and 6 for second black printed stroke from Canon LBP 3300 printer; numbers 7, 8 and 9 for crossing stroke***

Number	X	Y	Z	x	y	u	v	L*	a*	b*	u*	v*
1	0.541	0.546	0.549	0.331	0.334	0.208	0.316	78.8	-1.3	-0.3	-2.2	-0.2
2	0.767	0.775	0.755	0.334	0.337	0.209	0.317	90.6	-1.6	1.6	-1.3	2.5
3	0.872	0.879	0.845	0.336	0.338	0.21	0.318	95.1	-1.1	2.5	-0.2	3.8
4	0.158	0.149	0.192	0.317	0.298	0.213	0.301	45.5	5.2	-9.4	1.5	-13.1
5	0.229	0.229	0.245	0.325	0.326	0.208	0.312	55.0	0.0	-2.9	-1.7	-3.8
6	0.124	0.117	0.153	0.314	0.297	0.212	0.3	40.7	4.8	-9.2	0.8	-12.4
7	0.263	0.254	0.284	0.328	0.317	0.213	0.309	57.5	3.6	-4.8	2.1	-7.1
8	0.131	0.126	0.157	0.317	0.305	0.21	0.304	42.2	3.3	-7.5	0.0	-10.0
9	0.141	0.127	0.184	0.331	0.281	0.217	0.293	42.3	8.9	-13.3	3.5	-18.7

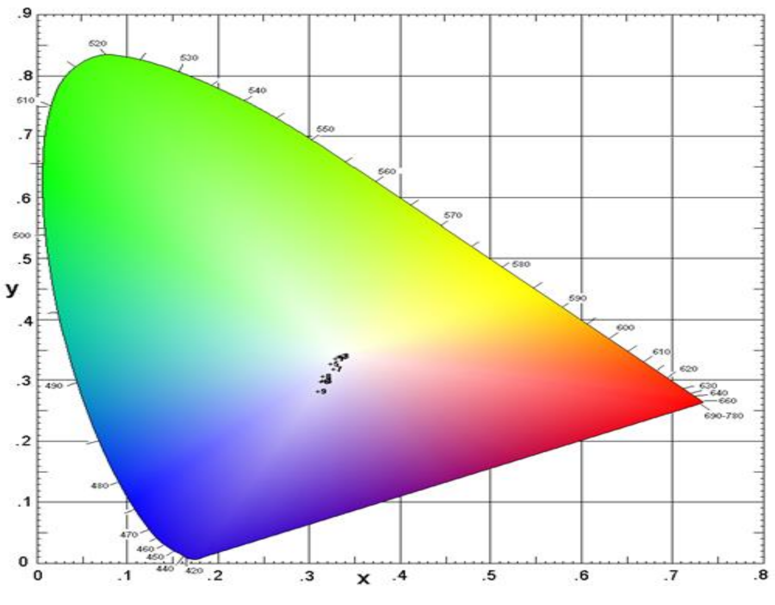

Figure 7: xy Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first black printed stroke by Canon LBP 2900 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 3300 printer; +7, +8 and +9 represent for crossing stroke

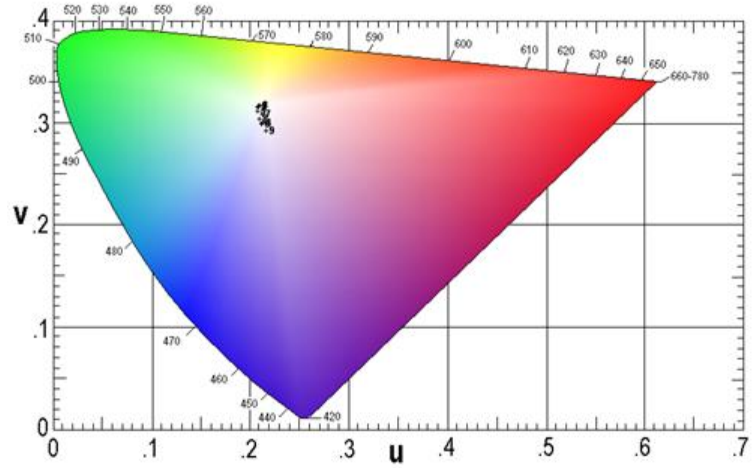

Figure 8: uv Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first black printed stroke by Canon LBP 2900 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 3300 printer; +7, +8 and +9 represent for crossing stroke

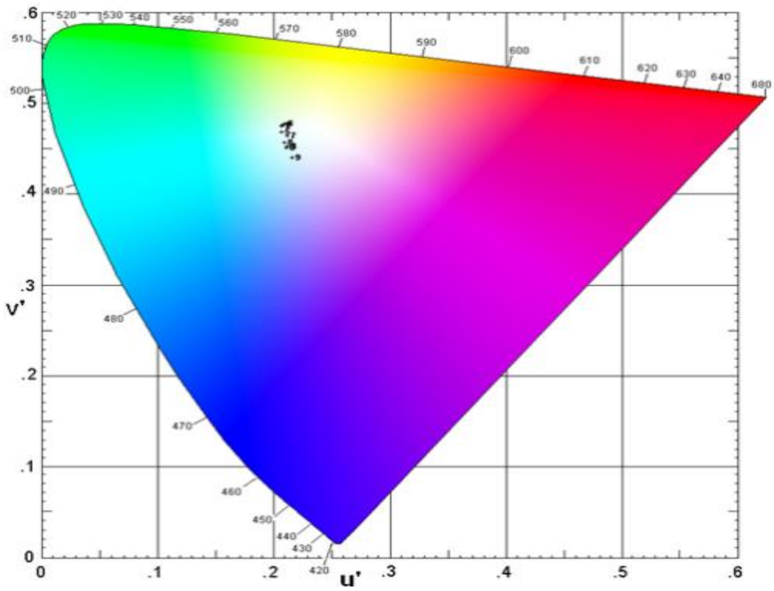

Figure 9: u'v' Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first black printed stroke by Canon LBP 2900 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 3300 printer; +7, +8 and +9 represent for crossing stroke

4.2.2 Heterogeneous Crossing Strokes

Heterogeneous crossing stroke means crossing lines of different colors. In this case also, heterogeneous crossing strokes are prepared from same as well as different printers. We get positive and convincing results in all these samples i.e. our experiment becomes successful to find exact order of sequence when two printed strokes of different colors cross each other. Here, one positive result is explained in detail where first red printed stroke is from EPSON L805 printer and second black printed stroke is from Canon LBP 2900 printer whose different chromaticity co-ordinates is represented in Table 4. For this sample, plot of obtained chromaticity co-ordinates in chromaticity diagram is shown in Figure 10, Figure 11 and Figure 12. In these diagrams, +1, +2 and +3 are for first stroke which are grouped to each other and are at different place than +4, +5 and +6 (for second stroke). Co-ordinates of cross stroke (+7, +8 and +9) and second stroke (+4, +5 and +6) are grouped at same place indicating that chromaticity co-ordinates of crossing stroke corresponding to second stroke which is according to our basic assumption. It indicates that use of chromaticity diagram for establishing order of sequence in heterogeneous printed crossing stroke is very useful to document examiners.

Table 4: Different chromaticity co-ordinates where numbers 1, 2 and 3 for first first red printed stroke by EPSON L805 printer; numbers 4, 5 and 6 for second black printed stroke by Canon LBP 2900 printer; numbers 7, 8 and 9 for crossing stroke

Number	X	Y	Z	x	y	u	v	L*	a*	b*	u*	v*
1	0.414	0.337	0.197	0.437	0.335	0.273	0.334	64.7	24.7	22.8	52.9	22.5
2	0.438	0.333	0.197	0.452	0.344	0.291	0.332	64.4	33.2	22.3	67.0	19.9
3	0.488	0.389	0.214	0.447	0.356	0.28	0.335	68.7	28.7	26.4	62.4	25.7
4	0.102	0.102	0.104	0.332	0.33	0.21	0.315	38.2	0.0	-0.6	0.0	-0.9
5	0.114	0.112	0.119	0.331	0.324	0.213	0.312	39.9	1.4	-2.0	1.1	-2.8
6	0.107	0.106	0.114	0.327	0.324	0.21	0.312	38.9	0.7	-2.3	-0.4	-3.0
7	0.114	0.115	0.113	0.334	0.336	0.21	0.317	40.4	-0.7	0.6	-0.3	0.7
8	0.102	0.101	0.102	0.333	0.331	0.211	0.315	38.0	0.8	-0.3	0.4	-0.6
9	0.116	0.116	0.115	0.335	0.333	0.212	0.316	40.5	0.4	0.1	0.5	0.1

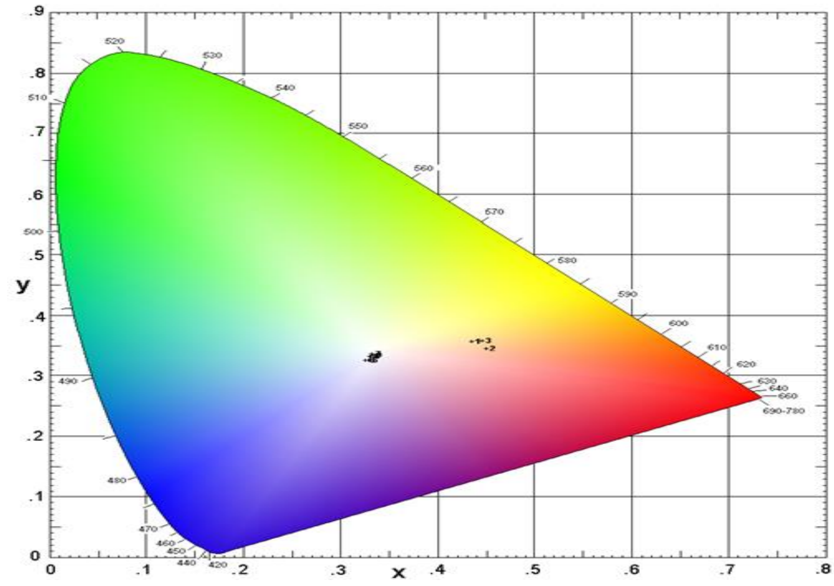

Figure 10: xy Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first red printed stroke by EPSON L805 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 2900 printer; +7, +8 and +9 represent for crossing stroke

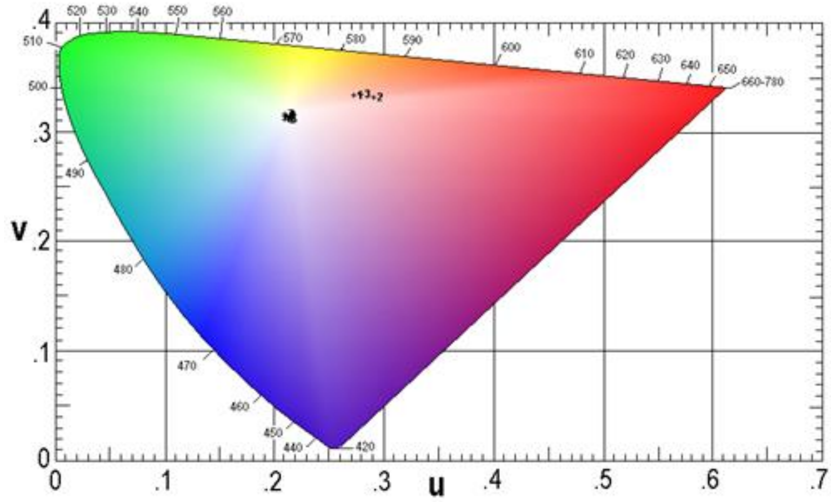

Figure 11: uv Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first red printed stroke by EPSON L805 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 2900 printer; +7, +8 and +9 represent for crossing stroke

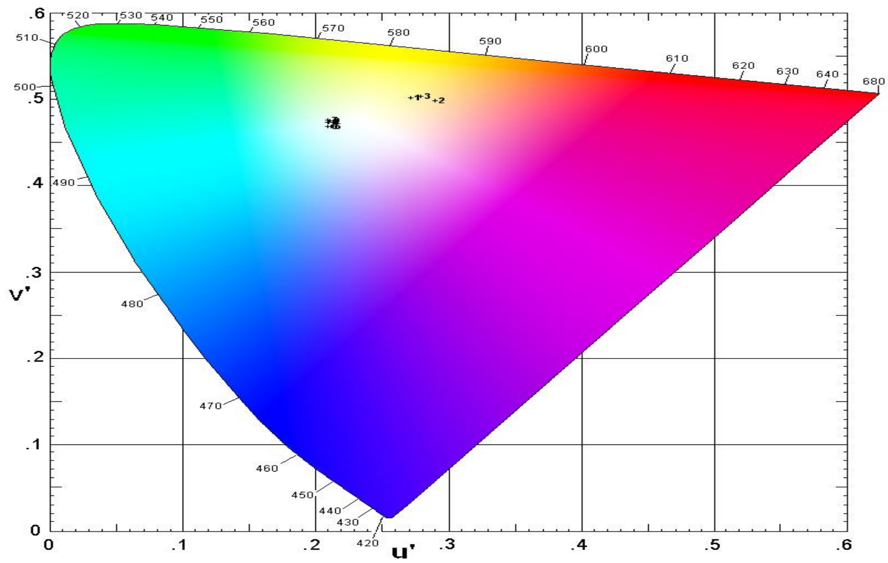

Figure 12: u'v' Chromaticity diagram generated by using Video Spectral Comparator (VSC)-6000 where +1, +2 and +3 represent for first red printed stroke by EPSON L805 printer; +4, +5 and +6 represent for second black printed stroke by Canon LBP 2900 printer; +7, +8 and +9 represent for crossing stroke

5. Conclusion

Result is very encouraging in the case of heterogeneous crossing strokes whereas experiment is totally failed to find order of sequence in homogeneous crossing strokes. On the basis of nature of sample prepared, this conclusion section is further divided into two subtopics as below and whole results are summarized as below.

5.1 Crossing Pen Versus Pen Strokes

- Completely negative and inconclusive results are obtained for all homogeneous crossing strokes.
- Also, negative and inconclusive results are observed in heterogeneous crossing strokes involving pilot pen (water-based ink) and cello pointec pen (gel pen).
- But we get positive and conclusive results only in heterogeneous crossing strokes by ballpoint pens (cello maxriter pen and cello technotip pen).

5.2 Crossing Printed Versus Printed Strokes

- We obtain completely negative and inconclusive results in all homogeneous printed crossing strokes (crossing stroke of same colors).
- But we get positive and conclusive results in heterogeneous printed crossing strokes (crossing stroke of different colors).

So, application of chromaticity diagram is found somehow useful to find chronological order in heterogeneous crossing strokes.

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