Sequencing Strokes in a Crossed-Line Intersection Using UV-Visible Microspectrophotometry

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Abstract

Development of a non-destructive method to sequence two markings in a crossed-line intersection is desirable and a UV-visible microspectrophotometer (UV-Vis MSP) can be used for this purpose through the collection and comparison of fluorescent spectra. This study is based on the hypothesis that the pen that is on top in the intersection will emit greater fluorescence than the pen on the bottom. Specifically, when the intersection spectrum is compared to control spectra, the control for the pen on top should share more peaks with the intersection than the pen on the bottom. These fluorescent spectra are measured in reflectance, which is why the pen on top will fluoresce more and have more shared peaks. However, there are still small amounts of penetration from the pen on the bottom, meaning it will also share peaks, but to a lesser degree. The results of this study show that different environments produced varying success of the sequencing.

Introduction

In a recent INTERPOL CCSD and AIEED study, the migration distance of a non-visible component of pen ink was used to determine the age of a crossed-line intersection (INTERPOL-AIEED, 2016). These components were visualized through luminescence when viewed under alternate light sources. Though this study developed a new, non-destructive method for ink dating, an equally important focus area is the sequence of intersecting lines, which is instrumental in determining authenticity. However, a variety of past approaches (both physical and chemical) have been used to try to determine the sequence of two crossed lines, though with limited success. This is due to the fact that in physical analyses, it is not always easy to resolve the two different strokes and in chemical analyses, there is consistently a contribution from both inks, making it difficult to interpret the sequence of the strokes. In addition, these chemical analyses are destructive towards the evidence. The combination of the limited success with past endeavors and the desire to preserve the evidence creates a need to develop non-destructive methods to accomplish stroke sequencing.

Objectives

The objectives of this research were to:

1) Establish a method that can reliably determine the stroke sequence
2) Observe the effects that different pen types, paper types, and environmental conditions have on the migration of the non-visible component
3) Determine the effects that different pen types, paper types, and environmental conditions have on the success of the method

Materials and Methods

<u>Six different pens were selected for this study:</u>

- 2 blue ballpoint (**A:** Office Depot ballpoint pen with grip, 1.0 mm and **B:** Bic Cristal Xtra Smooth, 1.0 mm); 2 black ballpoint(**C:** Bic Round Stic Grip Xtra-Comfort, 1.0 mm and **D:** Zebra Z-Grip Flight, 1.2 mm); and 2 black felt-tipped (**E:** Paper Mate Flair, 1.0 mm and **F:** Foray Stylemark, 0.5 mm)

Each pen was required to contain at least one luminescent component, which was confirmed using TLC, unique to the pen that it would be used in conjunction with for sample creation (ie: two black ballpoint pens).

<u>Five different paper types were selected for this study:</u>

(1) G: Strathmore Sketchbook Paper; Acid Free; **(2) H:** hp Colorlok Technology; Bright White InkJet Paper; **(3) I:** Recollections; White Cardstock Paper; Acid & Lignin Free; **(4) J:** Staples Copy Paper; 100% Recycled; and **(5) K:** Up & Up; Recycled Letter Printer Paper (30%).

These papers were required to not quench the luminescence of the ink, which was confirmed with an empirical study.

<u>Three environmental conditions were simulated:</u> heat and humidity for the crossed-line intersections and ambient for the control samples.

A CRAIC UV-Visible microspectrophotometer (UV-Vis MSP) was used to collect fluorescent spectra and subsequent quantitative data. UV-Vis MSP is a method in which the sample is irradiated by different wavelengths of UV light, which are then measured in reflectance to determine which wavelengths are absorbed. The results are visualized in the form of spectra. With the intersected lines, as time passes, the non-visible component of the inks migrate out beyond the intersection. The spectral data was collected from where the migration from each pen met, so that both inks were contributing to the sample collected. This spectral data was then used to confirm (as the sequence was known), the sequence of the two markings.

Results

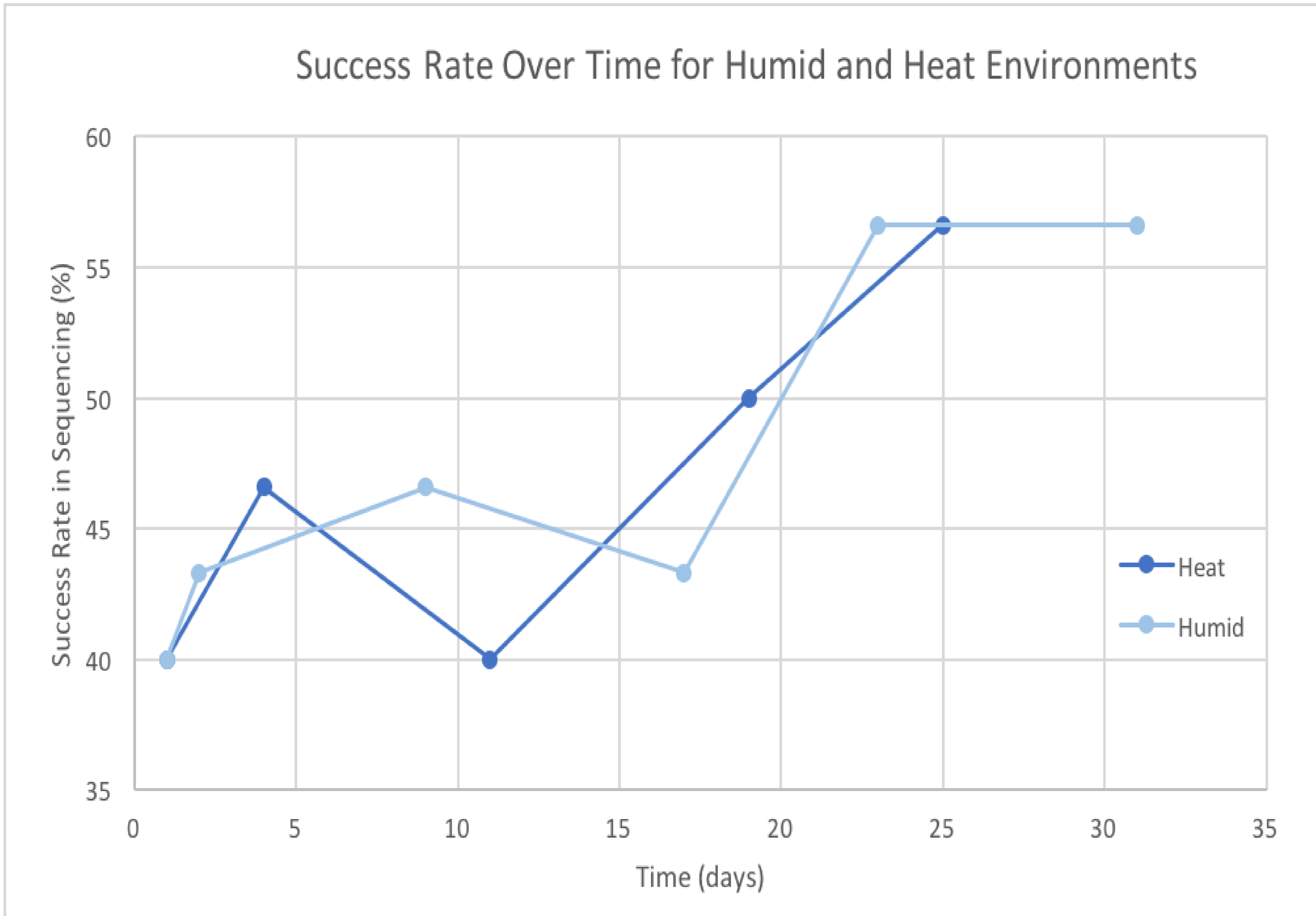

Figure 1: Success Rate Over Time for Humid and Heat Environments

A matrix with the intersection's (ie: AxB) important peaks in one column and one of the control's (ie: A) important peaks in a row adjacent was created; the absolute value of the difference between each data point was found. A match for fluorescent spectral peaks is defined as two peaks that are within 2 nm of one another. Thus, all peak value differences less than or equal to 2 were counted. I had hypothesized that the control from the pen on top will have more peaks in common with the intersection than the pen on the bottom. When this holds true, the method was considered to be successful in sequencing the intersection.

Heat	AxB	BxA	CxD	DxC	ExF	FxE	Total
G	2	3	2	1	3	3	14
H	1	4	1	3	4	2	15
I	1	2	1	2	2	3	11
J	2	2	2	4	2	3	15
K	4	2	1	3	2	2	14
Total	10	13	7	13	13	13	69
							69/150=46%

Figure 2: Heat environment's success totaled. "1" for success, "0" for fail, 5 days of samples analyzed.

Humid	AxB	BxA	CxD	DxC	ExF	FxE	Total
G	2	6	2	3	4	4	21
H	3	1	3	5	3	2	17
I	4	1	1	4	4	1	15
J	2	1	4	2	2	4	15
K	2	4	5	1	3	3	18
Total	13	13	15	15	16	14	86
							86/180=48%

Figure 3: Humid environment's success totaled. "1" for success, "0" for fail, 6 days of samples analyzed.

Discussion and Conclusion

Overall, the developed method was only moderately successful in sequencing the crossed-line intersections. The total success rates for the heat and humid environments (48% for humid and 46% for heat) were relatively low. However, in *Figure 1*, it is seen that the success rate increased as samples aged in both the heat and humid environments. It is also seen that the heat and humid samples often have comparable success rates. The effects of the environments on the migration were as expected: the humid environment fostered greater amounts of migration, whereas the samples in the heat environment had minimal observable migration. Paper G generally allowed for the greatest amount of migration and the other 4 papers allowed for equal amounts of migration. The felt-tipped pens migrated at the greatest rate because it's a liquid based ink; the black ballpoint pens migrated at approximately ⅓ the rate of the felt-tipped pens, which could be attributed to the paste-based ink; and the blue ballpoint pens migrated at approximately ½ the rate of the black ballpoint pens. In the humid samples, pens A and B had lower success rates than the other pens, which could be attributed to the fact that the non-visible component of the blue ballpoint pens migrated very little. However, in the heat samples, pens C and D had the lowest success rates. The success rates of the paper types were as follows in humid samples: G>K>H>I=J and in heat samples: H=J>G=K>I.

In conclusion, the results of this study warrant further investigation into the method. With an overall 48% success rate for humid samples and 46% success rate for heat samples, further analysis of additional data needs to be done in order to determine the success of the method from a larger sample size, rather than 6 and 5 days. A longer study would allow for further investigation into the increasing success rate of both environments. Using a UV-Vis MSP to obtain and analyze spectral data is a convenient, non-destructive way to sequence a crossed-line intersection, though the method to do so effectively needs further investigation and development.

References

(1) INTERPOL-AIEED (2016). INK DATING STUDY: MEASURING THE INVISIBLE MIGRATION. In *Physical-Chemical Study of Crossed Line Intersection* (CHAPTER 1. PROTOCOL A). Retrieved from https://www.interpol.int/.../Physical-Chemical-Study-of-Crossed-Line-Intersection

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