COMPARISON OF SIGNATURE ON PAPER AND APPLE® iPAD USING MULTIVARIATE ANALYSIS

LIM SUE XIAN

UNIVERSITI SAINS MALAYSIA

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COMPARISON OF SIGNATURE ON PAPER AND APPLE® iPAD USING MULTIVARIATE ANALYSIS

by

LIM SUE XIAN

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LIST OF SYMBOLS

H_0	Null hypothesis
H_1	Alternative hypothesis
μ_1	Ratio of signatures deposited on paper medium
μ_2	Ratio of signatures deposited on the Apple® iPad medium
%	Percentage
σ	Sigma

LIST OF ABBREVIATIONS

CV	Coefficient of Variation
DCS	Digitally Captured handwritten Signature
dpi	Dots per inch
FDE	Forensic Document Examiner
H	Total Height
LL	Lower Limit
LZ	Lower Zone
Max	Maximum
M/H	Middle zone ratio to total Height
Min	Minimum
MZ	Middle Zone
RSD	Relative Standard Deviation
SD	Standard Deviation
SPSS®	Statistical Package for the Social Sciences
U/H	Upper zone ratio to total Height
UL	Upper Limit
USM	Universiti Sains Malaysia
UZ	Upper Zone
QD	Questioned Document

COMPARISON OF SIGNATURES ON PAPER AND APPLE® IPAD USING MULTIVARIATE ANALYSIS

ABSTRAK

Transformasi dokumentasi sama ada dalam industri awam atau swasta yang sah telah bergerak dengan pendigitalan perniagaan di seluruh dunia dalam pecutan yang tidak diramalkan dalam dua dekad yang lalu terutamanya sejak pandemik Covid-19. Pemeriksa Dokumen Forensik (FDE) untuk kajian ini mempunyai permintaan tinggi untuk bergerak ke hadapan ke arah pemeriksaan dokumen digital sama seperti cara yang mereka lakukan untuk pemeriksaan dokumen fizikal konvensional. Tandatangan, sebagai salah satu ciri biometrik yang paling diterima oleh masyarakat sejak berabad-abad yang lalu, telah menjadi salah satu cabaran apabila tandatangan tulisan tangan ditangkap secara digital pada peranti digital dan bukannya kertas tradisional sebagai medium penulisan. Kebanyakan penyelidikan yang tersedia sebelum ini memberi tumpuan kepada data digital temporal untuk ciri-ciri tandatangan tulisan. Kajian ini bertujuan untuk menumpukan pada analisis nisbah ketinggian zon penulisan dalam tandatangan tulisan yang disimpan pada medium kertas dan pada medium Apple® iPad apabila kedua-duanya dianggap sebagai imej rata statik apabila dokumen digital tidak disediakan kepada FDE. Keputusan menunjukkan bahawa terdapat perbezaan untuk tandatangan pada medium penulisan yang berbeza berbanding prinsip tulisan tangan bahawa zon tulisan seseorang kekal secara relatif seragam dalam kebanyakan aspek. Pelaksanaan pendekatan statistik membolehkan peperiksaan tulisan tangan dibentangkan secara kuantitatif dan objektif kepada mahkamah undang-undang dengan menggunakan %RSD, k-means clustering, dan factor analysis sebagai kajian awal.

COMPARISON OF SIGNATURES ON PAPER AND APPLE® IPAD USING MULTIVARIATE ANALYSIS

ABSTRACT

The transformation of documentation either in legal public or private industry had moved with the digitalization of business around the world in an unpredicted acceleration in last two decades particularly since the Covid-19 pandemic. The Forensic Document Examiners (FDEs) for this study was on high demand to move forward toward digital document examination just like the way they did for conventional physical document examination. Signature, being one of the most socially acceptable biometric traits for the past centuries, has become one of the challenges when a handwritten signature was digitally captured on digital device instead of the traditional paper as writing medium. Most of the previously available research focused on the temporal digital data for the features and characteristics of handwritten signatures. This study aimed to focus on the height ratio analysis of writing zones in handwritten signatures deposited on paper medium and on the Apple® iPad medium when both were treated as static flat images when the digital document was not made available to the FDE. The results indicated that there were differences for signatures on different writing mediums as opposed to the principle of handwriting that the writing zone of a person remained relatively uniform in most of the aspects. The implementation of statistical approaches allowed the handwriting examination being presented in quantitative and objective opinions to the court of law by using %RSD, the k-means clustering, and factor analysis as preliminary study.

CHAPTER 1

INTRODUCTION

1.1 Background

In line with the evolving digital expansions, the mechanism of many industries is transforming into electronic with technological advancements to a paperless workflow by using e-signatures as an appeal to day-to-day business. It has been an rising trend, especially in banking institutions, insurance companies, hospitals and virtually every point-of-sale merchants to the emerging field of digitally captured signatures. It is undeniable that it creates challenges for forensic document examiners to be able to authenticate and examine electronic signatures just as they do with wet-inked signatures.

A document may be broadly defined as marks, symbols, signs, or any material displaying information that record past action and future intentions. The document examination is a discipline that assists the court of law into the need for investigation assistance in understanding the origin and history of evidence. The purpose of analysis does not limit to the authorship and authenticate the origin of source but also the ink and/or paper analysis and other elements of a document including addition or substitution, restoration, erasure as well as indentations.

A forensic document examiner (FDE) examines any documents about which a question has been raised concerning their authenticity, source, content, or age. One would require a forensic document examiner (FDE) for handwriting examination, altered documents, erasures, obliterations, indented writing, tracing, as well as inks and writing instruments.

Bank robbery notes, suicide notes, threatening notes, notepads or paper at the scene of crime can be useful for indented impressions examinations with the assistance of non-destructive electrostatic detection apparatus (ESDA) when indentation below the writing pages can be difficult to be detected using naked eyes. The non-destructive video spectral comparator (VSC) can detect alterations and obliteration. The ink examinations that are non-destructive techniques can differentiate inks but cannot identify if those inks are from the same writing instrument by infrared or spot integration.

Printing by different printers or multi generation copies documents may require examination by a forensic document examiner (FDE). Examination on staple holes on different pages within a bundle of document can provide useful information during document examination. Document and photograph staples before removing with permission and keep the staples with label as documentation.

Human is a creature of habits. Handwriting is a collection of those habits. Once the ability is developed, the writer redirects most of their conscious thought to the subject matter rather than the writing process (Osborn, 1929). It can be as individualized as a fingerprint.

1.2 Signatures

Signature has become one of the most socially acceptable biometric traits as it has been used in a financial and legal transactions for centuries. In contrast to public understanding, in which the digital image the of signature is a digital signature, a digital signature regulated by the Digital Signature Act 1997 (DSA, 2006) defines as below:

A transformation of a message using an asymmetric cryptosystem such that a person having the initial message and the signer's public key can accurately determine whether the transformation was created using the private key that corresponds to the signer's public key and whether the message has been altered since the transformation was made.

Digitally captured signatures (DCSs) are also known as biometric signatures, dynamic signatures, online signatures, electronic signatures, or electronically captured signatures. It refers to online system whereas dynamic signatures information is made available that includes feature-based system and function-based system. On the other hand, handwritten signature refers to an off-line system whereas traditional paper and pen or wet-inked are used to generate static signature images.

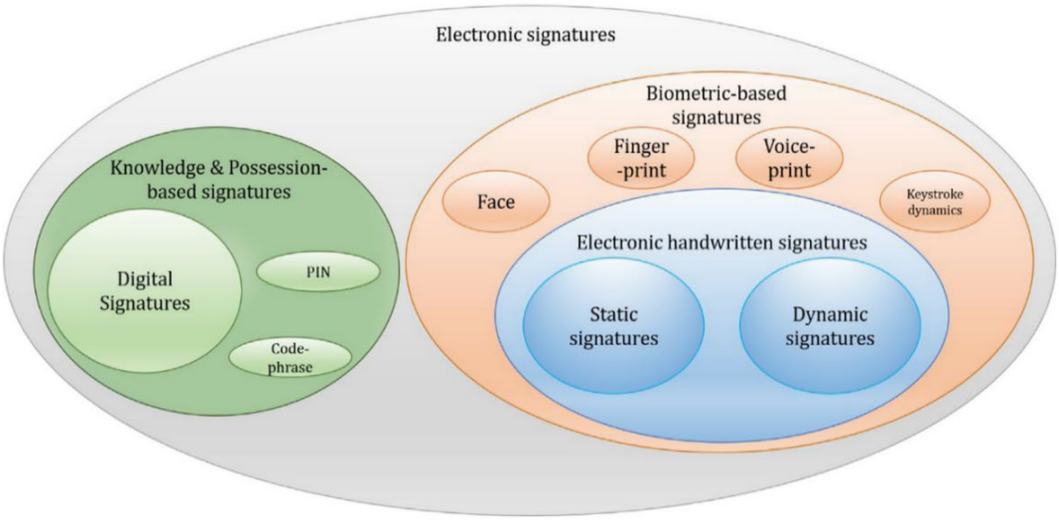

Figure 1-1 Nomenclature of electronic signatures (Linden *et al.*, 2018).

1.3 Signatures in Forensic Science

The questioned document has a long history and bright future as it is physical evidence. The beauty of physical evidence is that it cannot lie and its error is

misinterpretation or failure to discovery that deprive its value (Harralson and Miller, 2018).

In conjunction with the advancement in digital documents everywhere around the world including Malaysia, people are moving into using digital signatures from conventional paper and pen inking. Industries that fronting this include banking industries, insurance, healthcare and many more due to the convenience of signature that can be easily captured with many devices such as signature pads, tablets, smartphones, and stylus pen.

Hence, more and more signatures capture by digital devices require attention and analysis of forensic document examiners (FDEs). While verification using static image of signature is viable, it is proven that the dynamic features of digitally captured signature can reveal very discriminative information (Tolosana *et al.*, 2015b).

There are some of the writings and signing characteristic that remain relative consistent as one's writing habitual is derived from practice. Despite any deliberate or unconscious change in the primary or absolute size of writing, writing zone or proportion remains relatively uniform because of involuntary fixed pattern of a particular writer. It can be revealing as individuality and useful in the identification process. Ratios are also difficult to disguise (Osborn, 1929).

1.4 Ratio analysis in signatures

Writing is a complex motor skill. In the early stages, a child copies each letter presented to him or her consciously. As these are typically in a standard format, a copybook, the child's handwriting at this stage resembles that of his or her classmates and to that of other children taught using the same writing system. These shared characteristics are known as class characteristics.

As a child's skill increases, however, the act of handwriting becomes less demanding and his or her construction and other characteristics, such as shape and proportion, of character forms become more individualized. Such distinctive features are known as individual characteristics. The adolescent years are primarily responsible for the development of these traits. After this, a mature person's handwriting typically remains relatively unchanged until the loss of pen control associated with aging or other factors that cause it to change significantly once more (Huber and Headrick, 2017).

The total height for the sample is the sum of all the writing zone, the upper zone, the middle zone, and the lower zone. The total height was used to compare with all the three signing zones as ratio. Based on the scientific methodology of examination, the ratio of size remains (Osborn, 1929).

It takes movement through space to write. Starting at the imaginary baseline, writers work their way up or down to form their writing or signature. They follow guidelines that specify where each letter or strokes should be placed in relation to the baseline. The ideal ratios between the three writing zones, upper, middle and lower, are taught to writers (Koppenhaver, 2019).

The principle implies that the writer will write smaller when there is a limitation in the writing space. On the other hand, a writer may write bigger in conjunction with the space provided. Hence, signing or writing habits of a writer would remain (Osborn, 1929). The ratio analysis would not be affected with the shrinking or enlargement processing of signature or writing images by any form of reproduction as in scanning or photocopying unless distortion of images transpired.

1.5 Signature ratio in Forensic Science

The distinctive features of individual characteristic are used by the forensic document examiner (FDE) in conjunction with class characteristics to identify handwriting or signature of a writer. When analyzing questioned handwritten documents, the FDE compares all writing present including signatures and, based on his or her experience with scientific methodology, determines which handwriting or signature characteristics help make it uniquely identifiable. Under magnification, the construction, proportions, and shape of the individual writing or signature are observable (Stern *et al.*, 2018).

There are some intrapersonal variations in the patterns from one signature to another signature of a same writer just like handwriting. One of the basic principle of handwriting stated that no two handwriting is identical, even from the same writer or even a consistent writer, unless they are mechanically existed (Koppenhaver, 2019). To some individuals, these natural variations will be extreme; others might exhibit slight or virtually undetectable to unaided eye variation for being a consistent writer.

For writer with a wide range of variations, more samples and standards are required to reach a comprehensive conclusion. Writing can change over time. Some writer remains over time while others change drastically over a period of time. Hence, it is important to compare like with like as stated in the basic principle of forensic science.

Holding posture to writing instrument, position of writing instrument, performance of writing instrument, as well as writing movement are the basic constituents of handwriting. These attributes to a combination of writing habits of an individual which include lateral expansion and proportion.

One cannot exclude from one's writing habits or distinguishing characteristics of which he or she is unaware. In addition, one cannot include into his or her own writing habits or distinguishing characteristics of another writers of which he or she is unaware of the significance or presence (Ellen *et al.*, 2019). This is forgery in forensic context either by simulated or disguised writing. Forgers do not always hold on to the ratio of the writer they are copying, this implies to simulated writing. In addition, a person who disguises his or her own writing, using their common hand and uncommon, can hardly break away from their own writing ratio for the reason that handwriting is brain writing (Koppenhaver, 2019).

In the Questioned Documents (Osborn, 1929), it was stated as below:

The various parts of an ordinary signature when carefully measured bear a certain proportion to each other that with writers is found to be surprisingly uniform. There is a natural divergence, however, within certain limits, and an occasional exceptional part and this fact makes it dangerous to base a conclusion as to genuineness entirely upon a few measurements of size or proportions especially as expressed in complicated mathematical statements.

1.6 Writing or signing mediums

A document, within the standard rules of evidence, refers to any physical epitome of information or way of thinking such as receipt, diary, letter, contract or agreement, journal and many more. It refers to any material which contains either visible, partial visible, invisible marks, symbols, or signs that may convey a meaning or message. Pencil, or ink writings, typewriting, photocopies, printer generated materials, rubber stamps or seals, faxes, envelope information or postmarks, and even graffiti are included as documents (Mohammaed, 2022).

Writing or signing involves a writing instrument and a writing surface. Writing or signing mediums does not limit from stone engraving, lipstick marking on surface, for instances, a mirror, indentations by overlaid writing layer such as paper, to conventional instruments such as paper and pen or pencil to modern digital devices such as graphic pads, smartphone or tablet signing using stylus or finger and Apple® iPad using fingers or Apple® Pencil these days. There is an exhaustive list of writing or signing mediums.

Figure 1-2 Stone engraving

1.7 Forensic Research on Signing Mediums

Compared to DNA typing and fingerprint identification, the research efforts in document and handwriting analysis for identification in forensic science is at its infancy. Even though there were established methodology and standards that had been adopted and applied by the specialists and experts in this field, document and handwriting experts will not or may be reluctant to provide definitive answers to state in precise percentile or the probability level for their opinions or conclusions (Huber and Headrick, 2017). It is not due to the lack of their knowledge or confidence to do so but it is more of an issue that to reach a confirmative precise value to be given as an opinion in legal cases, references of research and results must be obtained first.

Conventional physical writing medium such as paper has a history for centuries. Digital writing mediums have been evolving for the past two decades. Writing mediums have a long history and a bright future. Unlike its counterparts that is the handwriting, research for signature was not given much attention in contrast (Ommen *et al.*, 2021).

Questioned Documents (1910) written by the Father of the Science of Questioned Document is a must-have book in the library of references to most of the forensic document examiners. The underlying principles for the classification and identification of handwriting are still hold up today. No one can write alike unless mechanically exists (Koppenhaver, 2019).

1.8 Problem Statement

Criminals are competing in new technology to achieve their objectives. It is necessary for the expert to stay ahead of criminals in the long run. Every case is a research problem that consequently requires a new approach in problem solving. Electronic technology has its effects upon handwriting and penmanship is no longer a principal goal in school, business and social (Koppenhaver, 2019). Hence, the approach to handwriting identification must be modified accordingly.

An individual's writing is influenced by the penmanship, physiology, emotional and physical condition during the act of writing, such as the writing instrument used, the surface in which it was written on, mood of the writer and even the solemnity of the content in the writing. Such difference is an individual variation and is termed as natural variation of the writer (Hilton, 1956). This variation has to be identified distinction has to be made to differentiate the writer's natural variation from the individual characteristics of the writer.

1.8.1 Factors That Influence Signature

According to Katherine Koppenhaver (2019), one of the Certified Questioned Document Examiner who possesses more than forty years experiences in the field, it is important to use comparison material written under similar circumstances within a specific timeframe as close as possible. It is particularly useful when the signature in questioned has been affected by some factor(s) that could result in the change of signature appearance. Once a writer has reached graphic maturity with permanent condition of automatic writing starting the age of eighteen, it will continue unless some mental or physical disturbance interferes with the ability to write (Osborn, 1929).

There are several factors that may cause variation in handwriting or signature. The basic factors that cause variation in normal writing include physical, mental, psychological, environmental, and mechanical factors. Dementia, being one of the mental impairments and mood swing in emotion can be contributed to mental factors. Drug or alcohol as in substance abuse, aging, medication, or health issues are physical factors that result in variation of a writer. Psychological refers to concentration on the act of writing, for instance, signing an important legal document versus a shopping list. Writing environment or condition includes a moving vehicles, extreme temperature or lighting. Mechanical factors comprise of writing instruments, the paper and the writing surface (Koppenhaver, 2019).

Mechanical factors were the main criteria of study for this research in term of signature, i.e., writing on paper and pen versus writing using Apple® Pencil and iPad. The use of some conditions as justifications for apparently poor writing is compelling. For instance, writing upon one's knee, or on a clipboard held in the hand, writing against wall, in a moving vehicles, while standing without stable support of

documents, or confined space and there are more exhaustive list of possibilities (Huber and Headrick, 2017).

It was highlighted by Huber and Headrick (2017) that there are six circumstantial factors that should be consider by an examiner. Firstly, the writing media employed. Secondly, the writing posture including stance and orientation to paper or medium. Thirdly, the writing purpose. It was then followed by space available and location together with surface and support. Finally, the circumstance also referred to the writing environment.

1.8.2 Lack in Signature Mediums Research

There was numerous research done in the handwriting to different writing medium for the identification and (or) differentiation of writers or writing mediums. In 2021, Nathalie from International Association of Document Examiners (IADE) found that the large letter formations remained in terms of the implementation of same general execution in pen and non-pen signatures (Bureau, 2021). In Nathalie's study, non-pen signatures referred to tablet-stylus and finger signatures in the relation to large letter, unique characteristics, terminal strokes, initial strokes, flourishes, omission of small letter, i-dots, t-crossings, slant, proportion of letters, compression of writing, connecting strokes, baseline, terminal dot, relation to signature line, and tick (Bureau, 2021). As opposed to the abovementioned characteristics, this study aimed to examine the ratio of signature writing zone in relation to quantitative measurement and analysis using different signing mediums.

In conjunction with Heckeroth *et al.* (2021), it was found that signatures deposited using finger instead of a stylus could result in more significant differences

in comparison with paper and pen signatures. Nonetheless, these dissimilarities did not show distinct signing behaviour that may lead to erroneous opinions in forensic context from the aspect of eight participating forensic handwriting examiners (FHEs). Caution should be taken when generalizing the characteristics of conventional signatures deposited with a pen on a pen and digitally captured handwritten signatures to practical relevance by examiners (Heckeroth *et al.*, 2021)

According to the study by a group of researchers in 2021, it was found that the numerical handwriting data in scaling information various not only by equipment used but also its software structure coding. It was a study with twenty-six different combinations of hardware and software highlighting the importance of digitally captured handwritten signatures (DCS) used to acquire the examined signatures in addition to the general approach in analysing signing conditions (Zimmer *et al.*, 2021). Despite signing mediums being the main focus of research, the ratio analysis was not core in signature analysis in the abovementioned study.

1.9 Rationale of Study

Opportunity came in when on-line system using digitally captured handwritten signature (DCS) employs digitized data and hence allowed some of the features to be extracted. It may be a potential feature to be used in handwriting identification under forensic scenarios. For this instance, this study focused on the variation of form of writing in which the writing zones of upper zone (UZ), middle zone (MZ) and lower zone (LZ) of signatures were studied in the comparison between on-line digitally captured handwritten signatures (DCSs) and off-line conventional paper and pen handwritten signatures.

The ratio or proportion is often individualized and therefore useful in the identification process. These ratios are especially reliable in handwriting examination as they are generally consistent from one writing session to another (Osborn, 1929). Furthermore, the ratio remains unaltered whether the document has been reduced or enlarged on digital imaging as well as the space utilization particularly the ratio sizing in relationship to upper zone (UZ), middle zone (MZ) and lower zone (LZ) as shown below.

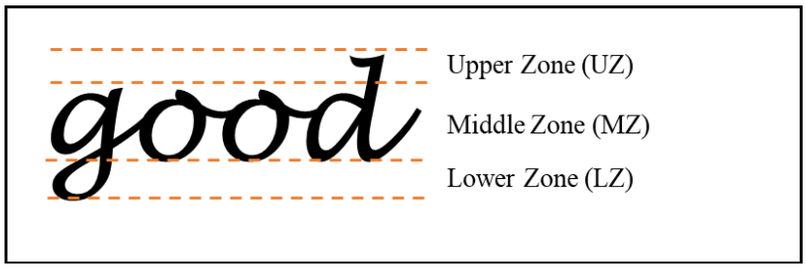

Figure 1-3 Illustration showing UZ: MZ: LZ in handwriting.

The motivation for doing this work was when we wanted to know if there were any significant differences when signatures were deposited on different writing mediums. The primary aim of this study is to focus on the handwritten signatures for the purpose of identifying ratios on wet-inked handwritten signatures on paper and digital devices. The scope of this study is limited to the study of handwritten signatures samples from the random population in Malaysia.

The importance of this study was to provide useful information for the field of forensic document examination where the writer signing on different writing mediums. The outcome of the result could be used as reference to forensic signature examination which may be applicable in contract agreement, company resolutions, suicide notes, will, or even graffiti on any surfaces.

The rational of this study was designed at the ground when a digitally captured handwritten signatures were made available only as printed hardcopy without the

presence of digital document, in which a digitally captured signatures became a static signature originally deposited on a digitizer, where a digital document allowed higher degree of authentication.

This study provided information on the different writing media, i.e., on-line (digitally captured) and off-line (paper and pen) signatures, from different writers. Being one of the significant individualized characteristics in handwriting, ratio analysis plays a vital role in handwriting and signature identification. Hence, it was used to compared and analysed in relationship from same writer using on-line and off-line signatures and extend to differentiation of different writers.

Statistical tools and modelling techniques were used to analyse and to form measurable differentiation for identification of different writers using ratio analysis of UZ: MZ: LZ. The study contributed to the significant power of differentiation using on-line versus off-line signatures dataset of different writers in the forensic document and handwriting examination in conjunction with the demand of tremendous application in digitally captured signatures.

1.10 Objective

1.10.1 General Objective

The general objective of this research is to use the samples of on-line (digitally captured) and off-line (conventional paper and pen) signatures to determine and differentiate different writers using ratio or proportion analysis of upper zone, middle zone and lower zone, i.e., UZ: MZ: LZ. The key element of this analysis is to determine if there is any distinct difference in the way a handwriting, particularly in signatures, may be affected in the determination of authorship on different writing media.

1.10.2 Specific Objectives

i. To examine and compare the writing characteristics for similarities and differences of different individuals particularly in ratio analysis using signatures collection on-line and off-line.

ii. To analyse the relationship between on-line and off-line signature characteristics using statistical analytical tools.

1.11 Research Question and Hypothesis

The research question for this preliminary study as proof of concept was to determine if a ratio of signatures deposited by the same individual on the conventional paper and pen is remained unchanged or significant different when different writing medium, i.e., the Apple® iPad, was introduced to the same writer. It enables a researcher or forensic document examiner (FDE) to confirm the inter-operability between the digitally scanned wet-inked handwritten signature on paper medium and the digitally signing on screen of the Apple® iPad on digital medium by the same person using ratio analysis.

The study was to prove the hypothesis by using ratio analysis of signatures with three zones, the upper zone (UZ), the middle zone (MZ), and the lower zone (LZ), the same signee of different writing mediums.

$$H_o: \mu_1 = \mu_2$$

$$H_1: \mu_1 \neq \mu_2$$

where μ_1 referred to the ratio of signatures deposited on paper medium and μ_2 referred to the ratio of signatures deposited on the Apple® iPad medium by same writer.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Forensic document examiner (FDE) analyses all aspect of a document in its materials and preparation, and changes over its lifetime. When we think about traditional document, our mind instantly showed paper, paper and books, pads, ledgers, a pile of paper on desk, and a stash in cabinet of hanging files. Digital file folders, just like the conventional file folders and that was how it got its name from. Indeed, paper constitutes of work, and it remains in a great amount of use despite the introduction of so-called paperless office.

Anything that communicating information that has potential to fall into the preview of forensic document examiner as evidence. A document is not just a piece of paper, but can be any media used to convey information, for instance, books, official identification, correspondence, receipts, contracts, graffiti, vandalism, etc. Labelling on a grenade, ketchup writing on a wall, bloodstain of dying man written in his own blood, to the journal of writer who wrote on website with logins and passwords, and personal financial documents of individuals or corporations, charities, and governments are examples of documents.

One of the most common ways of conveying information in the past couple of decades was by typed work. But that was not what exactly we are going to concern with in this study. Handwriting is a large component of a forensic document examiners (FDEs) analyses. Signatures are a special consideration of handwriting. This particular subset of handwriting namely handwritten digitally captured signatures was the focus of study.

A forensic document examiner (FDE) is trained to examine the full spectrum of possibilities. The full gamut of analyses includes to identify commercial or desktop printing identity, indentation development, shredded and torn document reconstruction, obliteration, alteration detection and restoration, line sequencing, absolute and relative ink dating, the list goes on and on.

Handwriting is a habitual biometric that is developed by a writer and can change over the course of the writer in his or her lifetime. Due to intrinsic and extrinsic factors, such as toxication and disease, it may be simulated by another writer or may be disguised by the writer himself. Comparisons are usually between questioned items and specimens. Handwriting is a whole that consist of cursive, printing, numeral, and signatures.

Writing is an act of repetitive skills until it becomes a habit. An individual would have reached his or her graphic maturity by the age of 18 and it remains until other influences cause it to decline. On the other hand, the handwriting of an individual may change gradually over time. The age of 65 is the threshold of an average person experiencing deterioration of handwriting caused by aging. While some maintaining handwriting to the age of ninety-year-old, most of the writers begin to deteriorates slowly at the age of sixty-five in general (El-Yacoubi *et al.*, 2019).

Traditional wet-inked signature is a handwritten personal mark or acknowledgement in fluid ink, dry graphite, or any physical material deposition (Campbell, 2022). A signature has been used to authorize transaction, laws, revolution, or daily personal correspondence. It is not commonly filed as a biometric. It is one of the oldest methods to identify a person including their intention. Indeed, its examination has been in forensic disciplines since the nineteenth century (Diaz *et al.*, 2019).

The digital age has brought forward many changes to how we human interact and exchange information. With much more telling have been done in the past two decades, with the arise of internet, and the corresponding increase in electronic commerce, society needed a way to a trustworthy exchange in the virtual world.

In the United States of America (USA), the Uniform Electronic Transactions Act (1999), or UETA, stated four points of legality. Firstly, the intent to sign. Secondly, the consent to do business electronically. Thirdly, the association with signature to the record writer. Finally, the record retention. It was facilitated in the year 2000 (Bonventre, 2021).

The electronic signature in global and national commerce act, e-sign in the United States, and the personal information protection and the electronic document act in Canada both provide the electronic equivalence to paper-based document and signature. The specification for capturing electronic signature are laid out in the standard of ISO/IEC 19794-7:2021 as information technology for biometric data interchange formats, the part 7 as signature or sign time series data (Campbell, 2022).

Europe has likewise created its European Union (EU) Regulation No. 910/2014 for electronic IDentification, Authentication, and trust Services (eIDAS). In October 2020, the European Network of Forensic Handwriting Experts (ENFHEX), being part of Expert Working Group of the European Network of Forensic Science Institutes (ENFSI), released a procedure for the examination of digitally captured signatures and handwritten entries as Appendix 5 to the best practice manual for the forensic document examiners for the forensic examination of handwriting (Zimmer *et al.*, 2021).

A forensic document examiner (FDE) analyses the design, skill, and fluency of execution when comparing known and questioned signatures. An inked line can be not just in two-dimensional construction but also the pressure that is imparted on the pen in

vertical dimension. A signature is assessed for its complexity showing the number of intersections and retracing of strokes, as well as the number of pen directions turning points. The complexity of signature can be ranged from low, moderate to high. The higher the complexity, the more difficult it can be simulated (Stern *et al.*, 2018).

Fortunately, a digitally captured signature (DCS) records same dynamic information. Comparison chart is used for side-by-side illustration of similarities and differences. It is not uncommon to see something like more complicated where many writings had overlaid each other that appeared to be signed by one individual's handwriting signature.

With metadata is perhaps the most overused phrase with albeit modest at its best, when data or more precisely metadata is going to be the new oil, where fuels driven the growth of economic more than a century, digital transformation. The combustion engine that refers to artificial neural networks-based deep learning in contemporary data analysis tool requires the use of this new "oil". Digital data has no limit and will be ubiquitous without ceasing in our lives on a daily basis (Khaw, 2022).

For the past two decades, we see the whole segments of document flow are migrated into the digital environment, let it be public services, banking as well as e-procurement. In 2018, a generation of biometrically activated digital signature and personal identification by handwritten pattern, a key stroke manner and facial parameters to be used for biometric authentication has been developed with comparatively high rates of reliability. It will then give rise to the variability of dynamic biometric patterns over time including on-line signatures approach (Lozhnikov and Sulavko, 2018).

The incorporation of electronic signatures which were captured digitally has created new challenges in forensic examination of handwritten signatures. With the

advancement in technologies, it has improved and compromised the capabilities of forensic examination in terms of acquisition and processing the forensic validation of handwritten signatures using biometric mode of dynamic (on-line) signatures. High level of inter-operability was presented in forensic context and also legal processes on trial basis (Sanchez-Reillo *et al.*, 2018). It is undeniable that research studies not only need to be validated scientifically but also acceptable in legal proceedings.

Forensic scientists from United Kingdom stated that the method of writing as well as the proportions in general can be used as a matter of habit. Although deliberate alteration may introduce little differences to accommodate disguise, the ratio between the height of loops and the middle zone of writing will remain largely unchanged. Practice may improve good copying but inaccuracies especially in the relative heights, shapes of loops, and spacing between capitals are unlikely to be avoidable (Ellen *et al.*, 2019).

2.2 Studies Related to Signatures Applications in Forensic Document or Signature Examinations

One of the major challenges in forensic science particularly in questioned document is the implementation of theoretical knowledge to practical skills. Many people often have the impression that it is easy to differentiate handwriting from different person. The application of signature examination as a potential tool of collaborative learning in a university in Switzerland showed that an extensive possibilities and limitations of signature comparisons were discovered. It is due to the limitation of experienced and practice together with systematic approach that are highly required for future practice. Mock cases improved critical thinking and problem solving abilities as well as be aware of challenges in real casework (Cadola *et al.*, 2020).

According to the guidelines for digitally captured signature, it is recommended to include relevant and adequate quality data need for examination. Despite being not a trivial requirement but can be critical for forensic signatory identification. To produce spontaneous and unaffected signature, it is of equally crucial importance to provide signatures with natural signing conditions. Those data would provide a solid basis in optimizing the use of digital captured signatures during examination in a recommended manner to achieve adequate evaluation and interpretation by forensic document examiner (Geistová Čakovská *et al.*, 2021).

One of the very interesting studies was carried out on self-identification of electronically scanned signatures and digitally constructed signatures in the United Kingdom. It was found that only 1% of the originators was able to identify all their own signatures correctly. These may raise concern about authentication judgement in governmental and banking employees in the real world as self-identification is not consistently possible. Forensic Document Examiners (FDEs) have demonstrated a superior ability to lay groups in distinguishing genuine and simulated signature. it raises potential complication when an author cannot identify a genuine “specimen” sample for comparison purposes (Kazmierczyk and Turner, 2021).

Online verification offers rich information for analysis by forensic document examiners, whereas dynamic features of electronic signatures are lost in offline verification. It was to be stressed that the “flat” picture of the signature do not provide FDEs with the necessary biometric information about digitally captured handwritten signatures (DCS) in serious limitations to the possibilities of signatory identification (Geistová Čakovská *et al.*, 2021).

This study was intended to use the method deployed by Bureau (2021), and develop a method to quantify and classify the effect of different writing mediums on

handwritten signatures either on paper medium or digital medium. It is an effort to address the requirement of the forensic science stakeholders, namely the trial of fact, the lawyers, the scientists, and the practitioners.

It is the duty of the forensic scientist to communicate their conclusions and opinions in a way that enable their audiences to appropriately use the weight of the evidence presented to them. The information should be presented in numerical, with a range or scale and verbal formats to minimize the variability from qualitative interpretations (de Barros *et al.*, 2021).

2.3 Studies Related to Ratio Analysis Techniques

Despite being frequently identical between different letters in the writing, the between the length of the loops and tails, commonly referred to as the upper and lower zone of the writing, and that of the main body of the middle zone, exhibits significant variance amongst writers. More subtle proportional discrepancies exist between writings of different authors than simple statements of height or width (Ellen *et al.*, 2019).

With the increasing demand of digitally captured signatures identification, it is vital to provide forensic evidence with proven statistical analysis of signatures captured from digital devices. In the study of dynamic (on-line) signature verification under forensic scenarios showed that a forged counterpart with 96.9% probability if the total signing requires more than 10 seconds (Tolosana *et al.*, 2015b). Whereas, ratio analysis remains relatively similar for specific writer either genuine or disguise (Osborn, 1929). Accordingly, height ratio of writing zone upper zone, middle zone and lower zone (UZ: MZ: LZ) plays a very important role in identifying different writers but it was not being carried out in previous research study.

Vertical proportions was mentioned in the study of Heckeroth *et al.* (2021). Being one of the features in the comparison of ordinal rating scale, vertical proportions showed 92% at zero scale which implied 8% of one-scale difference level in comparison of signatures of all questioned to known. Significant effects were found in almost all features with the application of ordinal model to the study of differences in signing conditions (Heckeroth *et al.*, 2021).

In the study of Lizega Rika (2018), the width and the heights of letters in handwritten texts were analysed. It involved the comparison of texts or allograph by using the technique of means of correlation as well as t-test value for the similarity of two texts in relation to its relative width and height. It was stated that the quantification techniques provided a numerical value to its similarity (Lizega Rika, 2018b).

A study conducted by Diaz *et al.* (2020) to investigate the common authorship of signatures by offline automatic signature verification applied k-means (k=3) clustering from singles features through all eight features. It was used to examine the optimal selection and divisions based on features with a complexity description applied retrospectively. A scatterplot matrix was used to evaluate this across the eight features. Each k-means clustering was assessed during three metrics including consistency, spread, and correlation (Diaz *et al.*, 2020). Clustering is a popular exploratory data analysis technique for gaining an understanding of the data's structure.

In Gupta and Kumar (2020), a passive model for identifying source printers was proposed. It is based on key printer noise features (KPNF), oriented fast rotated and BRIEF (ORB), and speeded up robust features (SURF) in forensic document examination system. The dimensions of SURF and ORB descriptor requires a large amount of memory for storing features. Thus, K-means clustering and linear programming problem (LPP) were employed. K-means reduced the descriptor to sixty

four cluster and LPP reduced into eight components each for both ORB and SURF features (Gupta and Kumar, 2020). The K-Means Clustering was introduced in this context to reduce the large amount of dataset into a more self-explanatory presentation.

2.4 Studies of writing mediums for Forensic Application

There are multiple layer types of electronic signatures. Differences in acquisition, storage format, intended use, some operated in the category of cryptographic, scanned hardcopy, static digital and digitally captured signature (DCS).

A so-called electronic signature, i.e., the cryptographic date and time stamped signature without the physical act of signing, is not habitual. Therefore, it is not considered a signature in forensic handwriting sense of the term. But only it can be used and applied to any means of general object identification. As such, it can only signal the computer was pressed or the field that the computer screen was tapped, but not who was actually operating the device. It may prescription in place that only allow certain person access to the computer, but this is often not the case. It may not be possible to prove who supposedly signed the digital document.

Conversely, the security of inked signature resides in a dynamic, habitual writing action of the signer in its strength wise in the lack of identical reproduction. Cryptographic signature alone can be useful for securing communication for transmission. It often provides no value for forensic evaluation of authorship as it can be seen, for example, there is not graphical signature to be found but only a line of text. The computer uses a click button which registers the so-called signer but would not confirm whose hand is on the mouse at the time of signing.

To many people, an electronic signature can also be a static image often a jpeg or a scanned inked signature that is digitally added to a document. It is almost no