COMPARISON OF SIGNATURES ON PAPER AND GRAPHIC PAD USING MULTIVARIATE ANALYSIS

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COMPARISON OF SIGNATURES ON PAPER AND GRAPHIC PAD USING MULTIVARIATE ANALYSIS

by

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

ctrl	Control key
gsm	Grams per square meter
mm	Millimeter
px	Pixels
+	Plus sign
®	Registered trademark

LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ACE-V	Analysis, comparison, evaluation and verification
CFA	Confirmatory factor analysis
CNN	Convolutional neural network
DCNN	Deep convolutional neural network
DPI	Dots per inch
DTW	Dynamic time warping
EER	Equal error rates
EFA	Exploratory factor analysis
FDE	Forensic document examiner
ICDAR	International Conference on Document Analysis and Recognition
LPI	Lines per inch
LZ	Lower zone
MATLAB	Matrix Laboratory
MZ	Middle zone
NN	Neural network
PC	Predictive coding
PCA	Principal component analysis
PDF	Portable document format
R	R Foundation for Statistical Computing
RPS	Resolutions per second
RSD	Relative standard deviation
SAS	Statistical Analysis System

SD	Standard deviation
SPSS	Statistical Package for Social Sciences
SVM	Support vector machine
TIFF	Tag image file format
t-SNE	t-Stochastic Node Embedding
UZ	Upper zone

PERBANDINGAN TANDATANGAN DI ATAS KERTAS DAN PAD GRAFIK MENGGUNAKAN ANALISIS MULTIVARIAN

ABSTRAK

Sebilangan besar sektor secara progresif menggunakan tandatangan elektronik sebagai kaedah standard menjalankan perniagaan kerana peningkatan teknologi dan daya tarikan aliran kerja tanpa kertas. Penggunaan tandatangan elektronik yang semakin meningkat telah memberikan cabaran bagi pemeriksa dokumen dalam kaedah pemeriksaan mereka kerana tidak adanya prosedur yang ditentukan dengan baik, penyelidikan yang berkaitan, dan perbezaan antara tandatangan elektronik dan tandatangan tulisan tangan. Sebagai langkah pertama untuk menjawab soalan mengenai perbezaan penulis tanda tangan dalam pelbagai medium, tandatangan dikumpulkan pada kertas Double A A4 menggunakan pena Ballpoint biru Grip X10 1.0mm, dan tablet pen grafik XP-Pen Star G430 dengan pen P01 Stylus. Kemudian, persamaan dan perbezaan antara tandatangan dianalisis menggunakan tiga parameter yang mewakili pergerakan dimensi menegak secara bertulis, iaitu nisbah zon atas dengan ketinggian total, nisbah zon tengah dengan jumlah ketinggian dan nisbah zon bawah dengan jumlah ketinggian. Parameter kemudian diuji dengan beberapa ujian. Nisbah digunakan untuk mengira purata dan sisihan piawai relatif dan seterusnya untuk analisis statistik. Ringkasnya, intra-variasi di antara pengarang terbukti, tanpa mengira media penulisan yang digunakan dalam tandatangan. Ini menunjukkan bahawa variasi semula jadi adalah umum, dan tidak ada orang yang dapat menghasilkan tanda tangan yang sama pada setiap kesempatan. Berdasarkan hasil statistik, ketepatan pengelompokan K-mean sekurang-kurangnya 60% dan lebih tinggi untuk semua penandatangan. Mungkin, ini menunjukkan perbezaan tanda tangan yang

ditulis di atas kertas dan pad grafik, walaupun orang yang sama menulisnya secara serentak. Dalam analisis faktor diikuti oleh plot penyebaran, tandatangan yang dianalisis dalam penyelidikan ini dipamerkan di dalam dan di antara media penulisan yang berbeza-beza. Variasi dalam menunjukkan bahawa variasi semula jadi diharapkan tanpa mengira media penulisan yang digunakan dalam tandatangan, dan tidak ada orang yang dapat menghasilkan tanda tangan yang sama pada setiap kesempatan. Variasi antara media penulisan, iaitu kertas dan pad grafik, terbukti, walaupun orang yang sama menandatanganinya. Oleh itu, hipotesis nol ditolak, dan hipotesis alternatif diterima di mana tandatangan dari orang yang sama akan berbeza ketika menggunakan media penulisan yang berbeza.

COMPARISON OF SIGNATURES ON PAPER AND GRAPHIC PADS USING MULTIVARIATE ANALYSIS

ABSTRACT

Most sectors are progressively adopting electronic signatures as a standard business method due to technology improvements and the allure of a paperless workflow. The increasing use of electronic signatures has presented challenges for document examiners in their methods of examination due to the absence of well-defined procedures, pertinent research, and differences between electronic signatures and handwritten signatures. As a first step to answer the question regarding the differences in signature writers in various mediums, 30 signatures were collected on Double-A, A4 paper using a blue Ballpoint pen Grip X10 1.0mm, and another 30 signatures on the XP-Pen Star G430 graphic pen tablet with a P01 Stylus pen from 5 subjects. Then, the similarities and differences between the signatures were analysed using three parameters that represent vertical dimension movement in writing, namely the ratio of the upper zone to the total height, the ratio of the middle zone to the total height and the ratio of the lower zone to the total height. The parameters were then tested with multiple tests. The ratios were used to calculate the mean and RSD and subsequently for statistical analysis. In summary, intra-variation among the authors was evident, regardless of the writing medium used in signatures. These suggested that natural variation was common, and no people could produce the same signature every occasion. Based on the statistical results, the K-mean clustering accuracy was at least 60% and above for all the signees. Perhaps, this shows differences in the signature written on paper and graphic pad, although the same person wrote it simultaneously. In factor analysis followed by scatter plots, the signatures analysed in this research are

exhibited within and between varying writing mediums. The within variation suggested that natural variation was expected regardless of the writing medium used in signatures, and no people could produce the same signature on every occasion. The variation between writing mediums, namely paper and graphic pad, is evident, although the same person signs it. Therefore, the null hypothesis is rejected, and the alternative hypothesis is accepted where the signature from the same person will be significantly different when using different writing mediums.

CHAPTER 1

INTRODUCTION

1.1 Research background

Forensic science is the implementation of science into the law. One of the first branches of forensic science was the study of forensic documents. Since the beginning, forgery has been a crime in any nation where writing and paper have been employed for commerce. As a result, the requirement for assistance in interpreting evidence relating to the preparation and subsequent treatment of documents led to the development of the profession of a forensic document examiner of questioned documents (Kelly & Lindblom, 2006). The work of a document examiner has historically centered on the analysis of handwriting and signatures on documents, the examination of official documents like passports, birth certificates, wills, mortgage documents, and banknotes, as well as the analysis of printed documents to ascertain the authenticity or origin of a document.

Document examiners are also responsible for examining documents' inks, papers, and other components to identify additions or substitutions, recover erased writings, and identify indentations (Agius *et al.*, 2017). The similarities and differences between questioned and known specimens were assessed through the comparison method and subsequently to reach an opinion regarding the source of a questioned document (Agius *et al.*, 2017).

Examining handwritten signatures is an element of document examination. A personal biometric is seen as unique to an individual, and handwriting is an acquired feature that mostly depends on culture and environment (Pervouchine & Leedham, 2006). The shape and size of some letters, such as loops and edges, spacing between

letters, the slope of the letters, rhythmic recurrence of the parts or arrhythmia, pressure on the paper as well as thickness of letters, all reveal the individuality of human handwriting (Agius *et al.*, 2018). According to Saini and Kapoor (2018), a person's handwriting goes through numerous stages of development. It first involves copying the letter designs taught by family members before incorporating more uniqueness.

A signature is a handwritten depiction of someone's name, nickname, or even a simple "X" or other marks that a person writes on documents as proof of identity and intent (NISTIR, 2020). Although frequently simple, signatures with a complicated, individualised design are commonly employed in our daily lives as tools for personal identification, authorship confirmation, document authentication, and verification. The comparison procedure evaluated the similarities and differences between the questioned and known specimens, and an opinion was obtained regarding the origins of a questioned document (Agius *et al.*, 2017). Signatures are highly personalised, automatic writing actions that need no mental effort to make (Kazmierczyk & Turner, 2021).

Modern technological developments will undoubtedly alter the field's terrain once more. Due to technological advancements and the appeal of a paperless workflow, most industries are increasingly adopting electronic signatures as a standard way of doing business. Many kinds of electronic signatures exist, such as personal identification numbers at Automated Teller Machine and cryptographic signatures (Becker *et al.*, 2021). However, handwritten electronic signatures, which include those obtained using digitising tools like a tablet or graphic pad and captured as photographs or as temporal and movement data, are the most popular type of electronic signature (Becker *et al.*, 2021). Due to the lack of defined procedures, relevant research, and the

differences between electronic signatures and handwritten signatures, the growing usage of electronic signatures has provided obstacles to document examiners in their approaches to examination.

According to Osborn (1910), the ratio or proportion of handwriting is often individualised and, therefore, valuable for the identification process. These ratios are incredibly reliable in handwriting examination as they are generally consistent from one writing session to another. Therefore, this study focuses on the vertical dimension of movements, the zonal movements consisting of upper (UZ), middle (MZ), and lower (LZ) zones of signatures to differentiate signatures deposited on paper and graphic pad.

1.2 Problem statement

Even with technological advances in this twenty-first century, handwritten signatures are the most often used form of authentication for checks and legal documents. Along with the developments, handwritten signatures have also been digitalised to sign electronic documents without using paper and pen. These digitally recorded signatures also called biometric, dynamic, electronic, or online signatures, are used to administer signed documents more quickly and inexpensively (Linden *et al.*, 2018).

Digitally captured signatures are created using a digitisation tool, such as a tablet computer or signature pad, and capturing software that incorporates a signature into a digital file. In banking, insurance, and healthcare businesses, graphic pads are used to get the client's signature on a formal contract or document. There are discrepancies between pen and ink signatures and electronic signatures, according to new research released by Natalie (2021), which examines the two types of signatures

from the same individuals. Therefore, it is worthwhile to investigate the variations in signatures between writing platforms.

While the analysis of a digitalised document falls into the competence of a digital forensic expert, the identification of the signee of a questioned handwritten signature resides in the field of forensic document examination (Heckeroth *et al.*, 2021). However, only a few studies provide forensic handwriting examiners with relevant information for comparing digitally captured signatures with signatures on paper to confirm the authenticity of a signature. This issue has barely been touched on whether the signing behavior with a stylus on a signature pad is similar to that of a pen on paper. Also, no article was published on comparing the signatures on different writing mediums using zonal analysis. This topic has scientific importance, but it also has a unique application to case studies where a questioned digital signature must be contrasted with a known pen and paper.

Comparing a digitally captured signature with pen and paper samples may pose problems. The article by Natalie (2021) used a conventional method to compare pen and ink signatures to electronic signatures. While the traditional way of forensic handwriting examination could be applied, the disadvantaged of using the conventional method outweigh the advantages. It is because traditional methods, including manual feature extraction and comparison, mainly rely on subjective criteria and are time-consuming. The subjective observation method of handwriting identification cannot effectively control subjective arbitrariness in the identification process, leading to questions on the scientificness of handwriting identification. Therefore, it is crucial to employ modern techniques in forensic document examinations to keep up with the trend.

1.3 Objectives

1.3.1 General objective

To determine whether there are significant differences between signatures prepared on paper and graphic pad.

1.3.2 Specific objectives

i. To obtain signatures from participants on paper and a graphic pad.
ii. To examine the similarities and differences between the signatures prepared on paper and the graphic pad using ratio analysis.
iii. To employ multivariate analyses to establish similarities and differences between the signatures prepared on paper and graphic pad.

1.4 Significance of the research

Most existing studies focused on handwriting rather than signatures, whereas many disputed cases involve signatures rather than writing. Thus, as a first step to answer the question regarding the differences in signature writers in various mediums, this research will tell us if there is any difference in signatures written on different writing mediums, namely papers and graphic pads. Moreover, the findings from this study can be used to examine signatures on paper and digital. Industries such as banking, insurance, and healthcare businesses depend on researchers who can develop research that will help them determine frauds from authentic customers.

Since ratios of handwriting zones are generally consistent from one writing session to another, this ratio analysis introduced is incredibly reliable in handwriting examination. It can be employed in the future by forensic document examiners or

researchers. Furthermore, the proposed method might help document examiners discriminate signatures written on paper and graphic pads. They will be able to distinguish signatures made by the same and various writers on different writing mediums and extend to the differentiation of different writers.

This work will contribute to filling this gap with explorative research investigating whether the differences in signing behavior between writing on paper and graphic pad are relevant for forensic examination. Furthermore, the study result is essential in the growing popularity of electronic signatures, which easily can be disguised in this era where the client's signatures are found on a formal contract or document. It also provides forensic handwriting examiners with relevant information for comparing digitally captured signatures with signatures on paper to confirm the authenticity of a signature. Moreover, this research is expected to determine if signatures from different mediums can be compared in a questioned document analysis.

This study's research was done computationally, and the data was analysed statistically where the technique is non-destructive, representative, reliable, cost and time effective. This signature analysis procedure could respond to the needs of the court and is focused on extracting individual characteristics to identify the signee of a piece of writing. Following these advantages, this research could help future researchers monitor forensic science's effectiveness in determining culprits using hardcopy or digital handwritten signatures as evidence.

1.5 Hypothesis

A hypothesis is tentative to answer questions regarding the research. The null hypothesis of this research is that the signature from the same person will be the same

despite using a different writing medium. The alternate hypothesis is that the signature from the same person will be significantly different when using different writing mediums.

CHAPTER 2

LITERATURE REVIEW

2.1 Signature examination

A signature is one of the most frequently used personal characteristics for verification since it is convenient, affordable, and accepted by people, government agencies, and courts. Criminals often conceal and fabricate signatures in an effort to produce fake documents (NISTIR, 2020). Simulated signatures attempt to mimic an authentic signature and all its dynamic characteristics (Kazmierczyk & Turner, 2021). In most cases, they are either freeform copied from a real specimen or traced with a lightbox, a sharp object, or a pencil to make an impression of the real sign that will serve as the simulation's guiding principle (Kazmierczyk & Turner, 2021). As a result, it is the responsibility of the forensic document examiner to identify and disclose false signatures.

Handwritten signature analysis is utilised for various applications by forensic document examiners when settling criminal cases. A forensic document examiner will conduct scientific examinations, comparisons, and analyses of a document to ascertain whether or not the document in question is genuine or to demonstrate that the document in question is a forgery by indicating the alterations, additions, or deletions that have been made to it (Lewis, 2014; Agius *et al.*, 2017; Detwiler, 2021). In addition, handwritten signature analysis is performed to identify or rule out people as the source of handwriting and, if required, to generate reports or testify in court to assist customers who hire the examiner's services in comprehending the analysis results (Agius *et al.*, 2017).

2.2 Principles of handwriting

Three main principles of handwriting can clarify the variation in the signatures of intra-writer and inter-writer (Lewis, 2014; Liu & Lian, 2018). The first rule is that, even with enough time and practice, no two persons can have identical handwriting (Liu & Lian, 2018). Using a signature in legal and financial operations is feasible due to specific traits in a person's handwriting that set it apart from others (Liu & Lian, 2018). This theory gives document examiners the ability to tell genuine writing from fake writing and to determine the signee of a sample of handwriting.

The second handwriting rule is inherent or intra-writer variances in all writing (Lewis, 2014; Liu & Lian, 2018). Therefore, despite multiple writing repetitions, two writing samples from the same signee will be similar (Liu & Lian, 2018). Because humans are incapable of machine-like precision and repetition, some variance in word creation style and tiny variations in all handwriting characteristics are expected due to the neuromuscular process (Liu & Lian, 2018). As it represents the changes and variations, frequently slight, noticed in repeated samples of one person's writing, variation is an essential component of an individual's writing (NISTIR, 2020). Variation more explicitly refers to the various ways a writer creates each letter or character, yet this variation is expected and adds to the personalisation and individualisation of writing (NISTIR, 2020).

The natural variety in an individual's writing style prevents samples written by the same individual from completely aligning when they are layered on top of one another (Koppenhaver, 2017). It is practically hard to duplicate all parameters precisely because the time, quantity, and speed required to coordinate an activity like handwriting are complicated and may be combined in many different ways (Koppenhaver, 2017). In this manner, a difference in performance between repetitions of an action by the same

person is possible and inevitable. Thus, the document examiner must learn to distinguish between natural variation and a different writer.

Writing is a difficult and highly developed skill, and numerous variables impact each writer's writing abilities, resulting in their distinctive writing style (Koppenhaver, 2017). These influences permeate the writer's work throughout their lives. Therefore, the third handwriting rule is that no writer should attempt to write better than they are capable of (Lewis, 2014; Liu & Lian, 2018). It means that expecting a perfect form of handwriting, even from someone who knows basic handwriting skills, is unfair (Lewis, 2014; Liu & Lian, 2018).

2.3 Factors contributing to the difference in the handwritten signature

According to Saudek (2013), a person can only write fluidly, effectively, and automatically if they are familiar with the letters, know how to spell the words, and do not need to focus on spelling. They should also be able to visualise the letters in their heads when they hear or see them mentioned in writing. He added that the writer should be free of any physical limitations that may prevent them from writing well.

Additionally, a writer tends to write fluently when using their native tongue (Saudek, 2013). Furthermore, he said that a person could write smoothly if they have control over their writing tool and the mechanical properties of their writing surface, paper, and pen are not in the way (Saudek, 2013). These assertions suggest that a writer has attained graphic maturity once they reach automatic writing, which lasts until a physical or mental condition prevents them from writing (Koppenhaver, 2017).

2.3.1 Mechanical factors

Mechanical factors such as the quality of the writing instrument, the quality of the writing medium, the position of the writer when writing, the lighting while writing as well as environmental temperature may play a part in changes in handwriting when a writer attempts to write (Koppenhaver, 2017). For instance, a broad pen point produces a different writing line than a fiber-tip or fountain pen; therefore, the type of pen used might impact writing (Koppenhaver, 2017). Similarly, the writing on a document might be affected by its quality because writing errors can occur on paper of poor quality (Koppenhaver, 2017). Moreover, the ink will penetrate some while repelling it from other materials when a paper is more porous than others (Koppenhaver, 2017).

If the writer has trouble using a pen or a piece of paper, they might have to adjust their writing pressure and speed, which will vary the indentations in the paper (Koppenhaver, 2017). On the paper, a rough writing surface can also leave patterns and grooves; meanwhile, writing on a softer surface causes a deep indentation in the paper, giving the impression that the pressure is heavier (Koppenhaver, 2017). The depth of the indentations in the paper might be decreased by placing a hard writing surface underneath it, and without sufficient support, the writer becomes inconsistent, which alters pressure patterns.

Koppenhaver (2007) also asserts that a change in body position, such as writing while standing, sitting, or lying down, may affect how the handwriting appears. Lighting can also impact handwriting, making it challenging to follow a line in dim light and temporarily blinding in brilliant light. In conclusion, efforts are made to create suitable writing environments.

2.3.2 Schooling environment

A school's institutional setting overseen by a teacher or instructor and offers a conducive environment for learning is referred to as the school atmosphere (Saini & Kapoor, 2018). Much of a person's handwriting is influenced by the educational institutions and writing practices that are commonplace in a particular geographic area. Saini and Kapoor (2018) discovered that a child's physical surroundings and the motor component of handwriting development often have a significant impact. Children who participate in physical activity show higher levels of motor activity than children who do not attend any physical education lessons. To a degree, the writer continues to be influenced by his teachers, which helps to spread graphical knowledge in a group in all three directions (Saini & Kapoor, 2018).

2.3.3 Culture or ethnic group

Additionally, it was noted that such growth varied significantly across diverse cultural contexts (Saini & Kapoor, 2018). Setting, experience, and culture all considerably impacted the essence or appearance of handwriting. The cultural context of a writer was thought to be a foundation from which the art of writing might be learned or developed (Saini & Kapoor, 2018).

The introduction of cultural norms like regularity and neatness, the implementation of cultural prejudices like slant, counter clock rotations, and transport from left to right, as well as the implementation of various limitations like stance, grip, and which hand is used, were all necessary for teaching handwriting motor preliminaries (Saini & Kapoor, 2018). According to Saini and Kapoor (2018), these norms,

prejudices, and restrictions may vary among cultures and societies, impacting writing differently.

2.3.4 Drugs or alcohol

Writing is a neuromuscular and psychologically organised activity (Graham *et al.*, 2006). On the other hand, drug or alcohol use had the potential to impair it, and the effects manifested first in the frontal lobe, where the superego's impact was lessened, then in the cerebellum (Aşicioğlu & Turan, 2003). Therefore, the decline in power was the cause of all hierarchical pressures and limits. Depending on the level of intoxication or medication, this could lead to improvements in mental, behavioral, psych neuromotor, and cognitive, as well as euphoria, logorrhea, enhanced self-confidence, emotional exaggeration, tremor, evidently untrained movements, a loss of synergistic movements, pupil accommodation issues, and ataxic movements (Aşicioğlu & Turan, 2003).

According to Aşiciolu and Turan (2003), using drugs or alcohol can also have noticeable impacts on a person's handwriting and may result in an amnesic state afterward. As a result, doubts about a document's legitimacy are raised (Aşicioğlu & Turan, 2003). Additionally, there had been an increase in incorrect spelling in handwriting produced when under the influence of drugs or alcohol. A person may also compose threatening notes that are anonymous or not and deny authorship afterward if they combine alcohol with medicines like triazolam (Aşicioğlu & Turan, 2003).

Besides, alcohol lowers inhibitions, resulting in larger, quicker handwriting (Koppenhaver, 2017). The writing becomes more garbled as the drunkenness level rises, where extremes in size and spacing will be observed (Koppenhaver, 2017). Alcoholics' handwriting will gradually deteriorate, resulting in uncontrollable muscle jerking and

tremor (Koppenhaver, 2017). Inconsistent ink strokes break in pen lines, and overwritten portions result in unpredictable behavior that lacks order (Koppenhaver, 2017).

2.3.5 Physical and mental health

Changes in writing abilities lead to variances in handwriting due to physical or mental health (Koppenhaver, 2017). A person's handwriting may change momentarily or permanently due to physical health conditions like illness and injury. Medication and other substances may also have an impact (Koppenhaver, 2017). Physical impairments include losing the ability to write with the preferred hand, eyesight, and aging also contribute (Koppenhaver, 2017). The writer's mental or emotional state may also affect how they write, making it appear more expansive and hastier when angry.

Additionally, handwriting may appear more compact when reflective and pensive, and when fatigued, the writing line and word endings may tend to droop (Koppenhaver, 2017). Dysgraphia is a mental disorder that has been classified as a learning disability. It can cause weak pen grasp, weariness, and cramping after a short period of writing, accuracy in copying and spelling, poor letter formation, writing style, and reading aloud when copying. According to Koppenhaver (2007), these conditions could contribute to handwriting differences.

Moreover, the overall writing of a person may be affected by confusion and dizziness, leading to line overlap and an off-balance baseline (Koppenhaver, 2017). Different effects on the work could result from changes in the writer's psychiatric condition. For instance, increases in handwriting size and writing that drifts upward are brought on by euphoria (Koppenhaver, 2017). Due to anxiety and restlessness,

handwriting may have erratic pressure, tremor, or other irregularities. Furthermore, the writing becomes slants and droops when someone is depressed (Koppenhaver, 2017).

2.3.6 Handedness

Suneet Kumar (2013) discovered that right-handed and left-handed writers' writing styles differed noticeably in specific features, including word slant, spacing, letter shape, and page margin. The signee also made a point of highlighting the fact that left-handed writers tend to make strokes in a right-to-left orientation and that the slope of the letters tends to lean backward (Suneet Kumar, 2013). However, the right-handed writer made strokes in the left to the right direction, and the slope inclined in the forwarding motion (Suneet Kumar, 2013). However, there were no discernible variations in the characters, such as pen pressure or word size.

2.4 Writing mediums comparison

Guilbert *et al.* (2000) discovered that participants relied more heavily on visual information to make up for the altered proprioceptive feedback. The investigations concluded that the smoothness of a tablet screen causes handwriting features to change, with the impact on graphomotor execution varying depending on the writer's level of handwriting proficiency. Although writing texts need more cognitive resources and feedback than signing, signing is considered a highly automated motor program, making it more resilient to changing environmental conditions. As a result, the substrate may have little to no impact on the signing behavior and therefore have little effect on how signature attributes change for forensic purposes. Guilbert *et al.* (2000) disputed the extent to which these results permitted a comparison between digitally acquired and handwritten signatures.

Research on the comparison of features between signatures written on paper, on the surface of a tablet device, and using a computer mouse was presented by Harralson, Teulings, and Miller in 2011. Three different writing tools, namely a mouse, a non-ink digital tablet pen, and an ink ballpoint pen on paper, were used by sixteen participants to sign their names on a tablet computer. Each of the three circumstances had a significant difference in length. The non-ink pen had a slower duration, and the mouse had the most unhurried period. The mouse was used to enhance vertical size (Harralson, Teulings & Miller, 2011).

Individual data in mouse and non-ink settings revealed an increase in intra-writer variability. It's because it was discovered while analysing individual data that some people attempt to get around the discomfort of signing with a mouse by making their signature simpler. Additionally, writers modify their signatures to fit the limitations of devices. Lack of immediate feedback might cause movements to slow down and vary in size or spacing (Harralson, Teulings & Miller, 2011).

They added that some electronics have instructions for writing inside a box or demand that the signature is written within a specified time. Some writers may alter their natural signature to fit it inside a box or to fulfill the time limit out of frustration with rejected signatures or reacting to instructions. Some gadgets can only be handled in one hand, which adds another potential source of bad posture when signing on a capture device. The authors concluded that forensic comparisons between paper signatures and digitally scanned signatures had some limitations. However, it's possible that these findings won't apply to contemporary capturing hardware (Harralson, Teulings & Miller, 2011).

On the other hand, Alamargot and Morin (2015) used second- and ninth-graders to write the alphabet, their first and last names, and surnames on a tablet computer and

paper to empirically show that using a stylus with a plastic tip has less friction than writing on paper with a ballpoint pen. The signees hypothesised that the smoothness of a tablet screen causes a change in proprioceptive feedback, which the writer counters by paying closer attention to how their handwriting movements are executed motorically. Using the tablet and the Eye and Pen program, kinematics was recorded. The name-surname task resulted in less readable writing from both groups, and they used more prominent characters on the tablet screen than on paper.

Also, compared to writing on paper, the ninth graders had tremendous pen pressure and a faster writing speed, while the second graders paused more often (Alamargot & Morin, 2015). According to Alamargot and Morin (2015), the two surfaces had differing effects on the writing of younger and older students. More particular, the ninth graders produced more giant letters and increased their pen pressure and speed to make up for the smoother surface, which is identical to the behavior seen in adults.

In 2015, Vera-Rodriguez *et al.* presented the architecture, acquisition procedure, and baseline assessment of e-BioSign, a novel database of dynamic handwriting and signatures. Five devices made up e-BioSign in total, including two Samsung general-purpose tablets and three Wacom devices (DTU-500, DTU-530, and STU 1031) made specifically to record dynamic signatures and handwriting (Samsung Galaxy Note 10.1 and Samsung ATIV). Data for these two Samsung tablets is gathered using a finger and a pen stylus to examine the effectiveness of signature verification in a mobile environment. Seventy subjects' worth of data, including dynamic information like their signature, full names, and number sequences, were collected over two sessions.

Also, the whole name and the signature were skillfully forged. A baseline evaluation of the signatures is performed for a predefined recognition system based on

dynamic time warping (DTW) to achieve a benchmark performance for each device. The outcome demonstrates that while using one's finger to sign produces acceptable results in the event of random forgeries (less than 1% equal error rates (EER)), the performance suffers dramatically in the case of sophisticated forgeries as compared to cases in which a pen stylus is used (Vera-Rodriguez *et al.*, 2015).

Besides that, Gerth *et al.* (2016) findings show that writing on paper and tablet computers differ in partially task-dependent ways. The results also demonstrate that participants could modify their graphomotor execution to the tablet computer's smoother surface while performing the tasks. The findings of their study offer a preliminary response to the still unanswered topic of whether the writing surface affects how proficient writers execute their writing movements. They discovered that using a tablet computer increased writing speed generally. It appears that the friction of the writing surface affects even seasoned writers, including the majority of adults. However, they can adjust quickly—even within ten items of replicating a specific word or phrase.

They used an experimental set-up in which the pen was mounted to a swivel arm in order to measure the difference in friction between the two surfaces. Different loads weighing 20 to 50 grams were linked to the swivel arm using a string that crossed a cable run at the end of the table to change the tractive force. For each material, the height of the pen, as measured from the surface, was the same. A counterweight at the opposite end of the swivel arm was used to maintain the same pressure on the pen during all tests (Gerth *et al.*, 2016).

The writing speed for each of the conditions was then calculated in mm/s. The data unmistakably demonstrates that the plastic-tipped pen on the tablet computer moves faster than a ballpoint pen on paper under all circumstances. They concluded that

the friction between a ballpoint pen and paper is higher than between a plastic pen and a tablet computer screen (Gerth *et al.*, 2016).

Devlin *et al.* (2016) also contrasted handwritten signatures with those digitally obtained. The study found that when compared to pen and paper signatures, digitally acquired signatures exhibit an increase in size, speed, acceleration, and average pressure. There were no statistically significant differences in the total amount of writing time. Although there were some differences across the signature types, it is unclear if these differences provide challenges for forensic casework or can be disregarded because of their negligible effects (Devlin *et al.*, 2016).

Heckeroth *et al.* (2021) compared the signatures on two different graphic pads and pieces of paper in their work. Along with paper, they also gathered signatures in STU-520 and STU-530 pads. In that study, 80 individuals wrote their samples on a signature pad using a regular stylus. At the same time, the writer sat at a table. Glass signatures were created by signing directly on the glass surface of the devices using the plastic tip styli that were included with the pads. The paper signatures were then contrasted with the hybrid ones to examine any potential effects of the signature pad's physical characteristics. The characteristics of the disputed signatures were evaluated and contrasted with those of known hybrid signatures.

In conclusion, this study found statistically significant feature differences between traditional pen and paper signatures and digitally acquired signatures. This is due to the conditions that come along with writing on a pad, such as the delayed and pixelated visual feedback of the writing trace displayed on a pad during the signing process, which may affect the signing behavior and therefore have an effect on signature features. However, based on the judgments of the document examiners who took part in this study, these discrepancies do not clearly point to a different signing behavior,

which runs the danger of leading to incorrect findings in a forensic context (Heckeroth *et al.*, 2021).

Samples were taken on paper and a tablet using a stylus and finger in paper Natalie (2021). The qualities that pen and non-pen signatures share precisely are the most significant. Stylus signatures constantly formed giant letters, any distinctive pre-existing traits, terminal strokes, starting strokes, flourishes, t-crossings, and connecting strokes. The huge letter formations, initial strokes, terminal strokes, and t-crossings of the finger signatures were identical to the pen signatures in every way.

The least detailed artifacts were the finger signatures, which revealed a general loss in compression and a more concentrated or strained attempt to generate. The improved adherence to the signature line indicates that more concentrated effort was put into signing. The palm and fingers move similarly while supporting a more challenging writing process, even though the finger signatures showed more degradation and variation compared to their pen equivalent (Natalie, 2021).

2.5 Signature zone analysis

Zonal movement takes place in the vertical dimension of the writing (Amend & Ruiz, 1980). Thus, a handwritten signature can be partitioned into upper, middle, and lower zones (Figure 2.1). The dimension of height, which is the vertical dimension, is seen in the proportion and movement of the letters upwards and downward throughout the writing zones. Graphologists typically utilise these characteristics to evaluate a person's genuine personality, which includes their behaviour, emotional outpouring, self-esteem, anger, imagination, honesty, fears, and many other personality qualities (Kedar *et al.*, 2015; Hemlata, Manoj & Kumar, 2018; Khanam, 2020). This trait

evaluates the spatial arrangements of signature where a strong habitual characteristic can be established using the zones system.

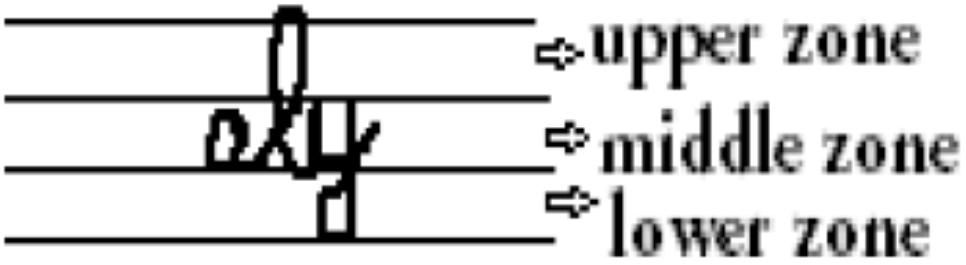

Figure 2.1 Handwriting that is partitioned into upper, middle, and lower zones.

2.6 Techniques for handwritten signature examination

Examination of handwriting samples involves various methods, depending on the aim and intention of the examination. In general, the techniques can be classified into two, namely, the traditional and computational techniques.

2.6.1 Conventional techniques

Traditional handwriting examination procedures are commonly used for answering questions about authorship involving the process of examination, comparison, evaluation, and verification, also known as an ACE-V framework (Agius *et al.*, 2017). The Canadian FDE Roy Huber created the abbreviation ACE, which stands for analysis, comparison, and assessment. A forensic scientist must proceed, consciously or unconsciously, through three stages to determine the identity of any person or thing. The analysis aims to identify writing characteristics such as size, slant, and letter construction, as well as more subtle traits like pen direction, the way letters are connected, and the distances between letters, words, and lines (NISTIR, 2020). These characteristics are what make up the total, whether they can be seen, measured, or inferred (NISTIR, 2020).

After reading and analysing the handwriting, the similarities and differences between the questioned writing and known writing were painstakingly compared, one at a time, and then the evidence was evaluated. Each distinguishing property of knowns and unknowns will be weighed or given a certain amount of significance (Lewis, 2014). Verification, which serves as a quality check for the examination, is the last step (Agius *et al.*, 2017). Then, a viewpoint is offered, ranging from ruling out a specific person as the signee of the in question writing to suggesting the person's identity (NISTIR, 2020).

2.6.2 Computational Techniques

Over time, the handwriting examination technique evolved into a computational method, although the conventional handwriting examination remains a routine practice in the discipline. Computational features could have removed the subjectivity of document examination toward a more objective feature extraction procedure (Srihari *et al.*, 2002).

2.6.2(a) Statistical analysis

Statistical analysis requires much computing and relies heavily on statistical pattern recognition algorithms because it is helpful when many features are present (Harralson, Teulings & Miller, 2011). The question document examiner could benefit greatly from the use of statistical models to help them deal with uncertainty (Srihari, 2013). After the handwritten features were retrieved from the samples, statistical methods for handwriting analysis employed the samples' perceived qualities with a user interface to calculate how frequently the characteristics and their combinations occur in the samples of handwriting (Srihari, 2013). After that, using the discovered frequency and considering the combinatorial possibilities and sample needs, one may create a

probabilistic graphical model (Srihari, 2013). These models estimate the likelihood of traits to ascertain if they are individualising and informing opinions.

The coding was utilised in the Heckeroth & Boywitt (2017) publication to analyse the FHEs' findings about the evaluation of the examination of authenticity. The sign of a number indicates whether the direction of the conclusion is accurate. Positive results show that a signature was successfully classified as simulated or that an authentic signature was evaluated as authentic. If a simulated signature was judged to be authentic or if an authentic signature was judged to be faked, negative values were given. This kind of methodology suggests that the result's certainty level increases with the absolute value of the number (Heckeroth & Boywitt, 2017). There are many statistical software exists to aid statistical analysis, such as Statistical Package for the Social Sciences (SPSS), Statistical Analysis System (SAS), Matrix Laboratory (MATLAB), Minitab, R Foundation for Statistical Computing (R) and more.

2.6.1.2(a)(i) Descriptive analysis

Practically all research projects rely heavily on descriptive analysis. The scientific method improves knowledge by observing phenomena, determining questions, developing hypotheses, testing those hypotheses, and then coming up with new observations, questions, and theories (Priya & Riya, 2021; Hayes, 2022). Descriptive analysis plays a crucial part in examining the world or a phenomenon, formulating research questions, and developing hypotheses based on what has been observed (Loeb *et al.*, 2017; Priya & Riya, 2021). Descriptive statistics can organise data into a concise summary by outlining the connections between variables in a sample or population. Before performing inferential statistical comparisons, descriptive statistics should always be calculated as a crucial initial step in research.

There are three main types of measurements used in descriptive statistics: measures of central tendency, measures of variability, and measures of frequency distribution (Yellapu, Kaur & Stoltzfus, 2018; Hayes, 2022). The centre of the data set is described by measures of central tendency using mean, mode and median. Moreover, the data set's dispersion is characterised by variability measures (Hayes, 2022). Measurements of variability or spread aid the analysis of how widespread the distribution is for data collection.

Variance is the final descriptive analysis technique as it establishes the dispersion or variation of the dataset (Hayes, 2022). The four primary ways to measure the dataset's spread are variance, standard deviation, range, and relative standard deviation (Hayes, 2022). To aid individuals in understanding the significance of the examined data, these two measures use graphs, tables, and general talks. Besides that, the frequency of data within the data set is described by frequency distribution measures. A distribution of values, or scores, makes up a data set. The frequency of every possible value of a variable can be condensed into numbers or percentages and displayed in tables or graphs (Loeb *et al.*, 2017).

2.6.1.2(a)(ii) K-mean clustering

A cluster is a group of data points distinct from data points in other clusters yet comparable to one another within the same cluster (Yadav & Sharma, 2013). These data points are sorted into clusters according to how similar they are in clustering, a technique for unsupervised classification. A clustering method aims to maximise similarity within clusters while minimising similarity between clusters (Yadav & Sharma, 2013). According to Siagian, Mulyono, and Fernando (2014), k-means is one of the most straightforward unsupervised learning algorithms that addresses the well-known clustering problem. MacQueen firstly proposed it in 1967.