UNIVERSITY OF KENT

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An examination of quantitative methods for Forensic Signature Analysis and the admissibility of signature verification system as legal evidence.

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CONFIRMATION OF OWN WORK

'I confirm that this report is all my own work and that all references and quotations from both primary and secondary sources have been fully identified and properly acknowledged in footnotes and bibliography.'

Signed …………………………………………… Date………………………………

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ABSTRACT

The experiments described in this thesis deal with handwriting characteristics which are involved in the production of forged and genuine signatures and complexity of signatures. The objectives of this study were (1) to provide sufficient details on which of the signature characteristics are easier to forge, (2) to investigate the capabilities of the signature complexity formula given by Found et al. based on a different signature database provided by University of Kent. This database includes the writing movements of 10 writers producing their genuine signature and of 140 writers forging these sample signatures. Using the 150 genuine signatures without constrictions of the Kent's database an evaluation of the complexity formula suggested in Found et al took place divided the signature in three categories low, medium and high graphical complexity. The results of the formula implementation were compared with the opinions of three leading professional forensic document examiners employed by Key Forensics in the UK.

The analysis of data for Study I reveals that there is not ample evidence that high quality forgeries are possible after training. In addition, a closer view of the kinematics of the forging writers is responsible for our main conclusion, that forged signatures are widely different from genuine especially in the kinematic domain. From all the parameters used in this study 11 out of 15 experienced significant changes when the comparison of the two groups (genuine versus forged signature) took place and gave a clear picture of which parameters can assist forensic document examiners and can be used by them to examine the signatures forgeries. The movements of the majority of forgers are

significantly slower than those of authentic writers. It is also clearly recognizable that the majority of forgers perform higher levels of pressure when trying to forge the genuine signature. The results of Study II although limited and not entirely consistent with the study of Found that proposed this model, indicate that the model can provide valuable objective evidence (regarding complex signatures) in the forensic environment and justify its further investigation but more work is need to be done in order to use this type of models in the court of law. The model was able to predict correctly only 53% of the FDEs opinion regarding the complexity of the signatures.

Apart from the above investigations in this study there will be also a reference at the debate which has started in recent years that is challenging the validity of forensic handwriting experts' skills and at the effort which has begun by interested parties of this sector to validate and standardise the field of forensic handwriting examination and a discussion started. This effort reveals that forensic document analysis field meets all factors which were set by Daubert ruling in terms of theory proven, education, training, certification, falsifiability, error rate, peer review and publication, general acceptance. However innovative methods are needed for the development of forensic document analysis discipline. Most modern and effective solution in order to prevent observational and emotional bias would be the development of an automated handwriting or signature analysis system. This system will have many advantages in real cases scenario. In addition the significant role of computer-assisted handwriting analysis in the daily work of forensic document examiners (FDE) or the judicial system is in agreement with the assessment of the National Research Council of United States that "the scientific basis for handwriting comparison needs to be strengthened", however it seems that further research is required in order to be able these systems to reach the accomplishment point of this objective and overcome legal obstacles presented in this study.

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1. Introduction

With the growing dependence on documents in modern society more care and caution is required in the signatures that are evaluating their integrity. This change in the value of documents in our society makes the work of a document examiner more challenging and demanding, placing new demands upon skill and new pressures on knowledge. As documents serve new purposes and acquire new values it is comprehensible and understandable that signatures on these documents are becoming a target for forgery more frequently. This is due to the fact that signatures play a vital role in order to verify a person's identity. In modern society, handwritten signatures constitute an established mean of personal verification that is legally accepted in all transactions with financial and administrative institutions. The main drawback of this method is the variations that frequently observed in the signature performance and the fact that they cannot be accurately estimated because writing is a complex motor process that is solely depending on psychophysical state of the author. This brings us to the conclusion that we should seek for innovative and robust methods to protect society from aspiring criminals. This necessity leads to the emergence of the field of biometrics. Handwritten signatures engage a very important role in the wide area of biometric traits. The concept of using computer-based handwriting analysis system containing large databases of handwritten signatures as authentication measures seems to satisfy the increasing needs of today's hi-tech society. This method is based on an automated analysis of handwritten data. In recent years there is a growing interest to automate the analysis process of an individual's handwriting for security reasons. This has as a starting point the fact that lately a general turn is shown towards the field of biometrics which has become more prominent. That is why the pattern recognition field has a growing interesting in automated the analysis of signature and bridging the gap between forensic document examiners and pattern recognition scientists. In this study we will refer to the capabilities of these systems as a complementary way of analysis of handwritten samples in contrast to the analysis made by forensic document examiners and try to ascertain if it is possible to use these systems in the court of law and therefore if judicial system can accept evidence derived from signature verification systems A future potential role for computer-assisted handwriting analysis in the courts is identified [1] [2].

A signature is the result of a specific pattern that the author decides to apply and through constant practise constitute a habitual aspect of every person's writing. The varying movements of the hand creates an individual's personal handwriting style, e.g. the connections of the letters, the size of the letters, the speed at which it is written, the continuity and uniformity of execution, hesitations and interruptions, and the pressure of writing are elements that represent the evidence of movement [3] [4]. A signature can be considered a form of cursive writing because it is rare to find someone who signs their name with block capital letters. In general there are two types of signature: signatures that resemble the cursive writing of the individual i.e. their signature looks like their name written in their normal writing style or signatures which include individual marks or markings, sometimes these signatures can be difficult to read. The person signing chooses what to include as their signature e.g. they may sign their whole name or just the initials of their first name/s plus the whole of their surname. On occasion the handwriting of an individual might appear to be unskilful due to the lack of handwriting tasks, however the signature might be a task that is performed for most of his/her daily transactions habits and characteristics in the signature may appear fluent [5].

Forensic document examiners agree with each other about the relative ease with which most handwriting features can be forged. However these assumptions and methodologies have not been tested in great extent under controlled experiments. Hence, research projects that are examining these assumptions and methodologies constitute an important support of the field of forensic document analysis, to which this study also has as an aim to contribute.

The primary aim of this project is to describe a quantitative approach which will demonstrate the relation between forged and genuine signatures. Until recently research which addressed the issue of signature authentication has mainly focused on static traces. However with the implementation of recent years technological innovations, researchers have the ability to quantify the kinematic features of signatures at the level of an individual pen stroke. Research regarding static features of signatures and how these features altered under different signing behaviours, in this study forged versus genuine signatures, can be supplemented by dynamic studies based on the kinematic method. With this method kinematic data are collected from signatures recorded on digitizing tablets revealing valuable information for the investigating behaviours [6]. This study gives an overview of the features and parameters that can be extracted from signatures using this approach in order to understand which of these characteristics of signatures are easier to be forged. In addition to this investigation another study regarding complexity of signatures will take place in this project. With the assistance of professional forensic document examiners we will make an effort to approach the signature complexity issue. Aiming to introduce quantitative methods which in the future may be part of the forensic experts' methodology, this study will examine the capabilities of the statistical model proposed by Found et al [7] by comparing its results to the FDEs' opinions regarding complexity level of signatures provided by the University of Kent database. Last but not least there will be a description of the legal status on accepting evidence derived from signature verification systems and what are the legal obstacles of this kind of evidence. Before proceeding with the practical investigation of the issues reported in this study, a literature review will be presented regarding the topics mentioned above.

1.1 Types of Signature Forgeries

At the point when a disputed signature on a document is given for examination, the most common request is to ascertain out if the signature is a simulated forgery, genuine or that the signature is composed by a specific author in view of a correlation with his/ her known written samples. Forgers try to make the best copy of the victim's signature so as their illegal intentions not to be perceived. A good attempt to forge a signature, in order to dodge suspicion, needs to satisfy two conditions. Initially it must be precise in construction and appearance. This can be achieved when the forgery is made in a slow and careful way [5]. Albeit there will be an unavoidable decrease in fluency. Signs of tremors, retouching, corrections, pen pressure without variation across the signature (see Fig.1.1 and Fig.1.2.), intense uncommon pen lifts and blunt terminal and beginning strokes are only some of the common signs of forgery [5]. Subsequently, the forger must write the simulated signature in a fluent and smooth way in order to have a natural result and to be consider as a convincing forgery. To accomplish this the mark must be composed rapidly and naturally as closely as could reasonably be expected from the genuine writer. However this frequently has as a result inaccuracies. Normally the average person finds it very difficult to copy both fluency and precision and by this way mimic the fine motor skills of genuine writer when try to forge the signature of someone else [8].

Fig.1.1. Pressure patterns of a genuine writer showing variety of pressure habits [9].

Fig.1.2. Writing lines showing even pressure across the signature which is an indication of forgery [9].

The forger seeking to form a successful forgery which would be very close to the original signature should try to imitate the motor skills of an original author and not implement its own writing characteristics when forming the forged signature [2]. Best forgeries probably achieved by imposters who exercise for a while with the target signature and come to the point where he /she will be able to copy it in the best possible way [10]. In this way gradually with practice a professional forger can imitate some of the target signatures characteristics and perform a forgery that closely resembles to the genuine signature [4]. However the forgers would never acquire the motor abilities of the genuine author and again there will be some differences from the genuine signature [2] [4].

Four categories exist to describe the cases of forged signatures. With their experience, scientists can identify a fake signature but it is more difficult to place a forged signature in one of these four categories [5].

1.1.1. Normal Hand Forgery

In the first category there are the occasions where the forger, without a specimen of the authentic signature to guide him, is attempting to forge his signature simply by writing the authentic author name. In this occasion the forger is not trying to change his/her handwriting or to achieve the best possible imitation of the authentic signature lacking the skills and the knowledge to perform a forgery of higher difficulty. Given the fact that he/she does not try to change his handwriting when writing the forged signature, with appropriate comparison material scientist can infer that it is forgery and who is likely to be the forger [5].

1.1.2. Free Hand Forgery

The most common type of simulation it is generated with the freehand method. With this method the simulator copies a model signature either with the model in front of them or from memory. The forger tries to make a pictorial imitation of the signature being copied. The person who attempts this kind of forgery pays attention to the obvious characteristics such as the appearance of the capital letters. It can be said that the letters are drawn rather than written in a physical manner. This kind of task is difficult to achieve due to the fact the motor task of handwriting is a very individual and complex task and trying to imitate someone’s signature is like mimicking the way someone walks or speaks. [11] The forger employs a model of the authentic signature to guide him in this type of forgery. The forger produces an artistic generation of the authentic signature. Forged signatures formed by the freehand method will have better line quality indicating smoother execution of the pen movement. Most of the forgers prefer to apply the freehand method in their forgeries. This simulation can be written with a more natural fluid manner but with this method of forgery it is difficult to forge the exact form and the proportions between the letters of the target signature. In this occasion, it is possible to have a very good simulation with identical similarity in relation to the genuine signatures, depending on the amount of practise and skills of the forger. [5] [11].

1.1.3. Tracing

In a traced simulation the forger has a genuine signature as a model which he uses to forge the signature. On this occasion the forger holds the genuine signature against a window or light box with another sheet of paper on top so it will be possible to outline the shape of the genuine signature. Carbon paper can also be used [11]. In the cut-and-paste forgery, a genuine signature is cut from one document and placed on the spurious document. Closely related to the cut-and-paste forgery is electronic forgery [11]. No two signatures or handwritings, even from the same person are ever totally duplicated. Just as certainly, total agreement between two, three or more questioned signatures is adequate demonstrative proof of tracing. Although there are not difficult cases to be solved this type of forgeries, it is precluded however to find the forger because there is no evidence of his handwriting in the forged signature. The forgeries made by the method of tracing is easier to have tremors signs indicating poor line quality. When there is an exact identification of forged in comparison with genuine signature, without the slightest variations, then we have case of traced forgery [5] [11].

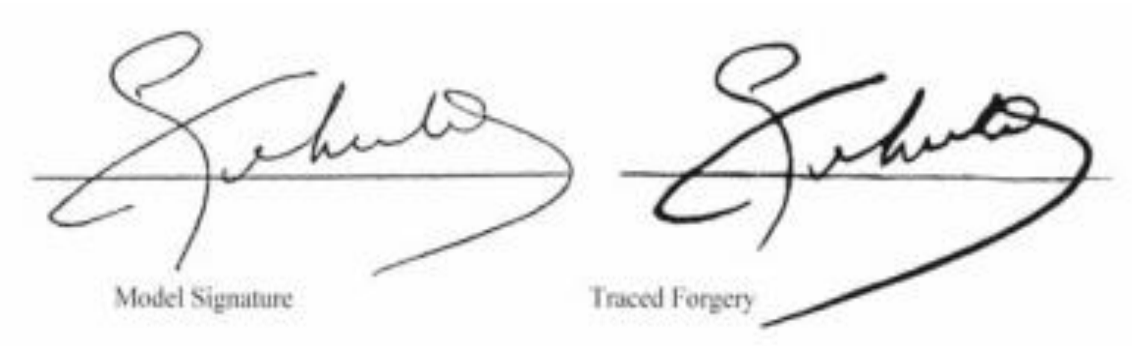


Fig.1.3. An example of a traced signature and the model from which it has been traced [9].

1.1.4. Auto-forgery

Initial observations of an auto-forgery often appear similar to what might be expected in a simulated forgery In these cases the original author, is changing some features of the signature in order to deny the authenticity of the later. Usually the forger is trying to change the letters size, the ratio between them or overall slope of signature. Although there is an attempt to change the structure and appearance of his signature, the signature will carry some specific information that have been acquired by the author through the years of practice and cannot be excluded completely. This information may reveal his unlawful act and intentions [5] [11].

Forged signature is a very popular topic so many articles have been published to date but it still remains a subject that interests the contemporary research. Various papers have focused in forged signature and specifically on the distinctive techniques used

Muehlberger has examined under which conditions it is possible to compare forged signatures with suspected forgers' handwriting and which characteristics seem to appear in forgeries [12]. A very interesting research and difficult to find similar one was this of M. Singh and S. Singh and Smith where they presented their real case experiences on forged signatures [13], [14]. Another attempt to reveal information about the methods of create disguise and forged signatures was this of Herkt. In this project overviewed 144 individuals trying to assemble data on the conceivable techniques of forged and disguised signatures. A thoroughly examination of the strategies used from each participant took place in order to decode how a forger acts in these occasions [15].

Leung et al., in a study of the simulation of letter-like abstract symbols, found that errors made in simulating all elements of proportion tend to exaggerate extremes; thus, long strokes are made even longer, small sizes are made even smaller, and so on. However, they did not report which elements are most likely to be imitated incorrectly [16]. In a study which shared some of the aims of this one, Lee et al. compared the success with which 62 Singaporeans simulated 12 specific features of a cursive signature. They found that slant, baseline, and size would present medium difficulty to simulators, while the instance of spacing would present high difficulty [17]. The relative sizes of letters have been suggested to be frequently ignored by forgers, and mistakes in their sizes are often mentioned in the literature as a sign of forgery (Osborn [18], Harrison 1981 [19], Hilton 1993 [11], Huber and Headrick 1999 [2]) [17]. Writing movement characteristics of the participants it was the main criteria used by Vardhan et a1. (1991) to distinct between genuine and forged signatures [20]. Bryan Found, Doug Rogers, Hermann Metz conducted a simulation experiment to test the software PEAT capabilities in signature verification and in objective measurement. In this investigation they chose the ‘one-off’ simulation as similar circumstances might take place at a transaction point. Researchers try to detect measurable spatial errors between genuine and forged signatures under this circumstance. In addition to this try to discover which parameter type can be associated with spatial errors and if this measurable data can of spatial errors can be used in daily work of forensic document examiners to discriminate between genuine and forged signatures [21].

1.2 Physiology of Handwriting

Limited research has been carried out specifically relating to the field of document analysis and physiology of handwriting. Only in recent years under the field of graphonomics has research started to be carried out. [2] Other research regarding the psychological perspective tries to identify how self-esteem, sex and social status, affect the overall appearance of handwriting [22]. In addition to this much work has been carried out around the matters of remedial approaches and pedagogy of writing in order to improve the understanding of handwriting generation and its quality in the writing of adults and children. [1] [23] [24]

Handwriting is achievable due to the combination of various processes. Different muscles work together during the handwriting process and due to this handwriting can be considered as one of the greatest tasks that the human hand can achieve. The hand is made up of twenty-seven bones which are controlled by more than forty muscles. Movements of the hand are under neural control, and the exact order and time of the actions determine the composition of the pattern that is recorded by a pen or other writing implement [1] [2] [25].

Habit is a very important factor for people, and occurs in every aspect of life including handwriting [26]. Due to the repetitive movement of writing it becomes habitual and the movements after a certain age becoming involuntary. Skilled handwriting is a combination of coordinated movements that fall into a strict sequence which are unique to each person. Over time the process becomes more automatic and less prone to outside control [1] [26].

Handwriting identification evidence is thought to be the most difficult to give [18]. This is due to factors such as different styles being used by one person, the ability to use both hands (ambidexterity), different health conditions or disguising of the writing, can make the work of the identification of one person’s handwriting even more difficult. To deal with these difficulties document analysis uses different methods such as pattern recognition and neuroscience to find scientific reasons for the individuality and uniqueness of human handwriting [1] [24].

Neuroscience is a new and promising field entering document examination because it studies the handwriting process from its neurological point of view and helps us to understand the anomalies appearing in handwriting. This valuable information can be used in the court of law by document examiners in order to explain some handwriting phenomena. The new discipline created through this examination of handwriting through neuroscience is called graphonomics which is considered to be the future for document examination. [1] [27]

1.2.1. General Normalities for the Examination of Signatures

Five key principles of handwriting identification have been recognised [1] [28].

1) No two people write exactly alike.

This is a well-accepted principle among document examiners. Each person, due to the repetitive movement of writing which becomes habitual, creates a certain pattern of writing features as they approach graphic maturity and no other individual can mimic exactly the same specific pattern. [1] [28] [29] [30]

2) No one person writes, exactly, the same way twice.

This is not statistically impossible, but it is generally accepted that no one person writes the same twice. Even up until today there is not one example or any evidence that can truly show genuine writing that has been produced exactly the same twice without it being considered to be a simulation [1] [28] [29].

3) The importance of individual's handwriting characteristics.

The importance of any characteristic, as evidence towards identifying or not identifying, and the difficulty of comparison, bearing in mind a rarity of features, the speed and naturalness under which the writing is produced, and its agreement or disagreement with the characteristic(s) to which it is being compared [1] [28].

4) A forger cannot copy completely a signature.

It is an accepted matter of fact that it is impossible for the forger to copy, remember and shape all the personal features of the author despite the fact that they can simulate the skill level and relative speed of the writer. Moreover the simulator will always try to copy all the writing features which are the distinct characteristics in their view. So for this reason the forger overlooks or fails to include subtle details which are very important indications for the identification of the writer [1] [28].

5) Disguise and imitation of handwriting

In the case that the writer successfully disguises his normal handwriting appearance and habits, and in the case that he attempts to imitate someone else's writing it is still impossible to not leave some trace of his handwriting in order to identify the person who attempted the imitation or disguise [1] [28].

1.2.2. The Fundamentals of the Signatures Identification Process

Signature identification by document examiners is accepted widely in legal and social terms and for this reason courts often ask for the examiners expert opinion to determine the authenticity of suspect signatures [3]. A document examiner has to be careful examining writing with a signature, sometimes contract and agreements are written out by one person and signed by another, however they may also have been signed by the first in order to attempt a forgery [29]. Just like handwriting, variation is found within signatures. Some people sign their name consistently alike whilst other people have huge variations within each signing [18]. Different circumstances and positions can affect the result of the signature e.g. if the person is having difficulty in writing [11] and that makes the work of a document examiner more challenging [1]. A signature is a specialised piece of work unique to each individual therefore the identification of it has a significant importance making the skills of a document examiner very specialised. [1]

Forensic document examiners use both analytical and scientific methods in order to give their expert opinion regarding the questioned document. [27] Their specialised work has to be performed in a precise, thorough and unbiased way in order to provide trustworthy and precise testimonial of their examination [1]. Forensic document examiners have to expand and maintain a wide range of knowledge within this field of expertise to allow him/her to respond and monitor the developments within a very demanding environment with continuous innovations and discoveries. Some of the areas that needs specialization and education are typescript and printing methods, various analytical methods regarding paper and ink, the deciphering of erasures and obliterations, laboratory procedures and quality assurances regarding the care and handling of documents and the presentation of findings during a litigation process [1] [27].

The skills of a document examiner are obtained through years of practical observations and studies, with constant examination of their skills to be able to give their expert opinions in court [1] [31]. A document examiner may spend their time analysing paper, inks and related materials for the aging and sourcing of a document [31]. However, the majority of the work of a forensic document examiner is held in the examination of questioned handwriting and signatures for the authentication or identification of the author or the detection of a forgery [1] [11]. To achieve this examination, the document examiner should always be looking for the most accurate handwriting and signature samples both temporally and quantitatively. In addition to this it is imperative to acquire like to like samples and this means that these samples contain the same characters and words written in the same style as the questioned document [1] [11] [27]. One of the most important stages in the examination of questioned handwriting and signature is for the document examiner to obtain several samples from the same individual in order to examine the author's variation in handwriting. To ascertain the author of the questioned document, examiners have to examine and take into consideration not only the individual characteristics but also the class characteristics. The term ''class characteristics'' encompasses the features in handwriting that are in common with a group of people who have learnt to write with the same writing system [2]. Class characteristics then evolve to individual characteristics when each writer adds a specific habit to the way that they are performing handwriting tasks [1] [32].

The basis of signature identification is very much the same as that for handwriting [1] [18]. The examination, of a personal signature follows almost all of the concepts relating to handwriting and vice versa. A signature may be nothing more than an extension of one's normal cursive handwriting, but there occasions that it may have been personalized to such an extent that it now has few, if any, recognizable letter formations [2].

However there are some problems in the identification process of signatures. The greatest problem for the identification of signatures is the small amount of comparable handwriting within the signature which may not include any of the author's characteristics of handwriting. This factor together with the natural variation makes signature identification one of the most challenging areas in forensic science [1] [33]. The basic aspects of handwriting and how a handwriting and signature analysis conducted will present. The understanding of the way in which handwriting is generated is of paramount importance in the process and development of handwriting examination systems, particularly in accounting for the variability of handwriting [1] [5].

1.3. Traditional Methodologies of FDEs

The forensic document examiner (FDE) pioneers based their methodologies in penmanship teaching. Their conclusions were based on the copybook systems deviations. They considered the copybook styles as class characteristics and the action of departing from these established standards as individual characteristics [34]. Their main methodology was based in these individual characteristics in order to decide if there was a simulation or the disputed handwriting were written by one writer or two. The majority of the cases examined by the FDEs is done on static image that is available for the expert to examine. However handwriting expert as recent studies showed have the ability to infer kinematic information from static in regards to speed, duration of handwriting, pen pressure and line quality [34].

One of the most important aspects in the document examiner's case load is to make the comparison between samples which are taken from a known writer with samples of questioned signature or handwriting, and decide if there is reasonable cause or connection to believe that two handwriting samples were written by the same or a different writer.

A well-known forensic document examiner David Ellen in his book states that evidence should be evaluated in regards of the subject' background knowledge. This means that to gain this knowledge an adequate sample of his handwriting or signatures must be taken into consideration for each subject in a forgery case so that the range of natural variation of the signature can be assessed [5]. In addition to this, another respectful expert Dan Purdy, advices that the examination of disputed handwriting should be based on a substantial combination of distinctive individual characteristics which will be detected in both the known and questioned handwriting [35]. Likewise the same range of handwriting variation should be exhibits in the known and questioned handwriting. Apart from a like to like assessment of letters and numbers other parameters must be taken into account that are difficult to be quantitatively evaluated. Parameters such as pressure, patterns, line quality, skill level and freedom of pen movement execution [36].

Furthermore William Riordan added that known standards of a handwriting case must be sufficient in quantity, contemporaneous and must be collected in a way to reproduce accurately the material in dispute. He also states “the methodology of forensic document examination is articulated emphasizing application of the scientific method to questioned document cases” [36] [37]. There are books and articles [2] [5] [11] [18] that give the right procedure and explain how this examination should take place in order for the document examiner to achieve the best results A brief reference will be made to some well-known methodologies applied by forensic handwriting experts and forensic laboratories in order to explain the way that a disputed handwriting/signature case is being examined.

The acronym ACE represents the parameters of Analysis, Comparison, and Evaluation. ACE is originated by Roy Huber, a Canadian document examiner, and enables a better understanding of the methodology the forensic document examiners apply in their daily work. According to him the work of FDEs is divided into three categories [36] [38]. There are three stages, in order to verify the identity of one individual, which must be implemented by the expert in his/her examination. First the questioned item must be categorised in regards with its most distinct characteristics or properties. These characteristics must be directly measurable, implied or observable. Second a comparison is made between the unknown item characteristics with the known item whose identity and characteristics is unquestioned and have already recorder. Last the evaluation stage takes place. Here the weight of evidential significance of each item properties must be considered in order for the expert to reach a conclusion for the questioned item [38].

Another methodology that would be useful to report is based on the work of Scientific Working Group for Questioned Documents (SWGDOC) that was formed in 1997 with the primary aim to address the necessity for standards in the forensic document community. SWGDOC's technical experts produce standards and submit them to ASTM International organisation for reviewing and publication. A methodology which is widely applied by the experts is ASTM Standard Guide for Examination of Handwritten Items E2290-07a (ASTM, 2013) in the framework of the ACE concept [39] [40].

In 2003 a general approach in regards to forensic handwriting identification and comparison, that is applied by Australian and New Zealand government practitioners, was reported by Forensic Expertise Profiling Laboratory at the La Trobe University in Australia by B. Found and D. Rogers [41]. The flow diagram, as it was called, consisted by 10 stages that depict the handwriting examination procedure. These stages are:

1. Handwriting sample presentation and contamination
2. The determination of whether specimen and questioned entries are comparable
3. Comparison of handwriting samples
4. Non-original handwriting

5. The assessment of handwriting complexity

6. Structural and line quality dissimilarities (line quality features are dynamic)

7. Traced writings

8. The simulation process

9. Line quality and skill

10. Reporting procedures

Huber and Headrick's [2] methodology with 21 basic elements that are useful to FDEs will be partly reported in order to have an in depth view of this well-accepted work by this field experts and therefore to be possible a comparison with the quantitative methods proposed in this project.

1.3.1 Connections

Using the term, 'connecting stroke,' implies a distinct entity, identifiable as a pen or pencil stroke between or connecting two letters. Connecting strokes are the several ways under which joins are made linking terminal strokes, bars or spurs, and first strokes, despite that the initial stroke may be primary or secondary in nature. Concerning the production of signatures, connections may be quite significant. The signature's producer may copy the letter designs, however they may overlook a rational repetition of the manners under which letters are joined together. It is not unheard of for a writer to tie words together, and the simple occurrence of these kinds of unions can offer a valuable contribution to the putting-together of writing habits of an individual [1] [2].

Fig. 1.4. Letters joined by rounded connecting strokes called garlands along the baseline [9].

Fig. 1.5. Letters joined by arched strokes above the baseline [9].

1.3.2 Dimensions and Spacing

Careful and close study of the signatures will reveal many elements of proportion which has a relation with the size of the components of a signature and the overall appearance of a signature. This factor is very important for the signature identification process due to the habitual relationship between the spaces which usually exist between letters and the width of each letter. Although it is nearly impossible to maintain the exact correct proportion of movement between the elements of signature this examination is always taking this into consideration, due to the fact it is revealing a general pattern of the writing of each person [1] [2] [4].

Interlinear spacing is something which is given by lined paper. Only on plain paper can you truly see how much space an individual uses in their writing. People who produce small handwriting, lines on a page are fine, however for people whose handwriting is larger the lines may appear cramped or crowded and the loops for the letters such as g or y may become entwined with the writing on the line below it [1] [2].

1.3.3 Arrangement

'Arrangement' is a collection of habits influenced by the ability of the writer, the way in which the writer senses proportion and the implement they are writing with. Arrangement can be seen in the way that the text is placed and balanced. Arrangement is closely related to margins. Sometimes the balance of the text is seen as the respect of the margins to the left or to the right of the page, but not so much the margins which appear on both the top and the bottom of the page. Margins can determine the placement of a text on a page. On a normal sheet of A4 lined paper it is common for the writer to take notice and respect the presence of the left hand margin whereas the right hand margin is generally overlooked. The presence of margins on the page should not be overlooked. The top and bottom margins may be different sizes to the right and left margins. All four margins may all be of different dimensions [1] [2].

1.3.4 Slant or Slope

Habit appears to exist in handwriting which is a task consisting of a collection of habits. Due to the repetitive movement of writing it becomes habitual and the movements after a certain age become more involuntary. The same appears to happen with the angle of the writing of each individual. Slant or slope, also consists of a factor with a paramount importance in the identification process. Within signatures a certain letter may be angled more to the right (or to the left) than others. The general slope of a signature may be common, however, the pattern of variation in slants or slopes in the upstrokes, and variation in the angles of down strokes becomes complicated and hard to imitate effectively [1] [2] [4].

1.3.5 Proportion-Ratio

The most significant element that is taken into consideration during a handwriting examination is proportion. Letters may be written in different sizes and slopes but it is the relationship with the other figures or letters that is the most important. This element of handwriting examination is consistent even in cases with disguised writing [42]. The ratio of the letters that construct the signature is considered to be an obscure writing habit and a factor that always has to be examined during the signature identification process. For this reason much research has to be undertaken in accordance with the reasons that affect the natural variation of writing elements proportion. An aspect of this topic will be examined in this research project [1] [2] [42].

1.3.6 Alignment

One of the most important elements in handwriting examination is alignment as a habit in the writing of each individual and should always be carefully considered. In addition to this deviations and alteration in alignment can be caused due to changes in movement and especially of the position of the writing arm in relation to the line of writing [1] [2] [18].

The skill to put the letters in a certain position is acquired during the period that a person is learning the formation of written characters. This is due to the eye to hand movement that each person learns as he/she matures and develops, thus becoming a part of a writer's habitual characteristics. The changes occurring from this habitual movement and therefore baseline alignment is a very important factor to rule if a signature has been forged or not [1] [2] [18].

1.3.7 Embellishments- Diacritics and Punctuation

The examination of punctuation, diacritics and embellishments also have a significant importance in the examination of signatures and handwriting and are consistent throughout the whole writing process. Punctuation and diacritics are marks that are used in the writing process to clarify the meaning of certain sentences and show in which part of the word the reader has had to use a higher or different sound value to show the difference from other letters and words. Conflict can arise around the small size of the punctuation and diacritics marks, how is this possible to identify one writer with? When a person uses punctuation marks, this could be in unity with the rest of the writing elements. This could be a strong piece of evidence for the identification of the author as the same consistency could occur on the embellishments that a writer uses [1] [2].

Fig. 1.6. Example of idiosyncrasies and embellishments that the writers develop.

1.3.8 Line Quality

Line quality dissimilarities (dissimilarities observed in terms of writing pressure, fluency, writing speed and skill levels between the sample writings being compared). The definition that Huber gives for line quality is that “Line quality is the degree of regularity (i.e., smoothness and/or gradation) to the written stroke as may be judged from the consistency of its nature and of its path in a prescribed direction. It varies from smooth and controlled to tremulous and erratic”. A number of other names can be used to explain the meaning of line quality. For example fluency is the term that is used by Harrison [19] and stresses that it is impossible for fluency to exist in the disguise execution. Freedom of movement appearing in the writings of every person is a further explanation for line quality, Huber also uses the terms “skill and freedom” and describes freedom in writing as something which is shown in the direction, consistency, and ‘clear-cut’ feature of the strokes of the pen or writing implement [1] [2].

Line quality dissimilarities are indicators of non-genuineness, dissimilarities observed in terms of blunt starts and stops, fluency writing, speed skill levels and writing pressure, when genuine and forged handwriting sample are compared. These dynamics parameters of handwriting are what examiners evaluate in order to reach a conclusion and may include the following. Blunt starts and stops are presented in cases where the forger finish writing the forged name lifts the pen from the surface of the paper and this may cause a valuable blunt start or ending in terms of the forensic examination. Also in a forgery there may be unnatural and inappropriate marks by pen starts and stops that will be considered as indications of extrinsic intervention into the normal writing of the original author. Another factor that helps evaluate line quality are hesitation and pen lifts. This happens when a sudden change in direction of the letter formation or there is a new letter formation in genuine handwriting. In order to complete the forgery task the forger is usually to perform hesitation and pen lift in these point of writing where are not present in genuine handwriting construction. Furthermore are the elements of tremor and pressure. The line of handwriting when is producing in a smooth way is resulting in a smooth movement in contrast to forger where the pen is moving slowly the ink line remains constant in thickness, resulting from the same constant pressure exerted on a slowly moving pen. Last as regards to line quality is the parameter if patching. Very often when writing the signature mistakes are possible to be made and it is possible an individual to attempt to correct the inaccurate part of the signature. These mistakes are taking place due to the difficult body posture during writing or an imperfection in paper or pen has affected with the normal handwriting appearance. The attempts to correct these mistakes are usually patent with the intention to make the signature more readable and surely without the intention to mask or hide the correction. On these occasions the writer detects an obvious defect in the appearance of signature and he attempts, by using patching, to make it passable in order to deceive [2] [25].

Fig. 1.7. An illegible signature rapidly written, showing smooth lines that represent good line quality [9].

Fig. 1.8. Slow writing showing poor line quality [9].

1.4 Natural Variation in Handwriting and Signature

Reference has been briefly made to the variations found within the writing of one person, especially differences in overall appearance due to speed of writing and other factors. In these conditions, much of the detail described above will remain unchanged, and characteristic or unusual features will still be found. Natural variations are normal to occur within the handwriting of each individual. These differences in handwriting may be affected by various circumstances. Even under these circumstances, e.g. with different writing implements, variations in handwriting performance will occur within a matter of degrees [5]. Natural variations are normal to occur within the handwriting of each individual. These differences in handwriting may be affected by various circumstances. Even under these circumstances, e.g. different writing implement, variations in handwriting performance will occur within a matter of degrees [1].

As handwriting is practised these variations will decrease because writing skill and control will grow, however, a person will never totally be without variation in their handwriting. Sometimes, if a person’s writing is skilled these variations will not be totally visible to the naked eye but a scientific instrument, such as a microscope, will uncover them. There are various forms in which as individual can sign a document. There are some cases in which a person, after a lot of practise, can produce signatures which are very similar to the genuine one. In other cases there are people that can use more than one signature to sign a document or in a specific design, according to the document being signed. Also a semi-literate writer who is not trained in writing may produce signatures with a high variation ratio [1] [43].

There are always some letters between a person's signatures that will be different every time. As mentioned above, one of the five major principles of handwriting and hand printing identification is that "No one person writes exactly the same way twice". No writer can be so consistent in his writing, in ordering the letters from the alphabet that they use to be exactly consistent. They could be exactly superimposed as it can happen with two printed letters. However, the most important fact for a document examiner is that most individualised characteristic of each person will remain unchanged, and characteristic, even if unusual features can still be found due to variation [1] [2].

Keeping in consideration all of the factors mentioned above a document examiner must also think about and compare other factors such as the size of the signature, the degrees of slope, line quality and how the letters curve, in order to separate the cursive and the capital letter texts of individuals. There are so many letters and so many different variables available for each of these letters that it is practically impossible that compared handwritings will resemble each other in all respects. Theoretically it isn't totally impossible; however, the chances of it happening are very slim. It can be true to say that each and every person has their own unique style of handwriting, but, it is not possible to say that that individual's style could not be matched by someone else. This is why a document examiner requires as much text or as many samples as possible because the more material they have the more features and characteristics used by one person will be greater than the features and characteristics of the other person, so no chance match will be found [1] [5].

1.5 The Variables that can Affect Handwriting

There many factors and circumstances that could contribute to irregularities occurring in the performance of an individual's handwriting. Some of these factors could cause serious deterioration in the performance of the writer and some could just alter certain characteristics of the writer [1] [2]. Of greater importance is how the following variables, both intrinsic and extrinsic, affect the individual author.

1.5.1 Illnesses

Illnesses related to the nervous system and motor skills could cause deterioration or loss of fluency upon one's person writing. Lower handwriting results in quality, erratic results, distortions of the usual shape of the letter and omissions of letters are some of the expected results of these conditions. In addition to these results, irregularities in the general appearance and changes in the pressure one writer applies to his/her writing are also common phenomena. The loss of consistency according to the writer's previous appearance is something that could be expected, although this does not mean that the writer, due to this circumstance, loses all their previous writing habits there are still some recognisable aspects which persist and maintain in the person's writing. Illnesses related to the nervous system and motor skills include: Parkinson’s disease, Multiple Sclerosis and Alzheimer's [1] [2]. Research conducted by Wellingham-Jones found that Multiple Sclerosis can greatly reduce the ability to perform fluency and control in handwriting [1] [24].

1.5.2 Medication

Medication is well accepted in handwriting examination as one of the causes of alterations and irregularities displayed in writing elements. However there is limited research of these effects regarding the document analysis field and how these side effects influence FDE’s examiners decisions. Roy A. Huber mentioned “The effect of drugs (i.e., medications) on handwriting is dependent on the type of drug administered, the individual’s sensitivity to it, and the points at which the handwriting is sampled during drug treatment” [1] [2]. Other medication that can cause alterations on handwriting is the medication L-Dopa used to control the abnormalities in movement for Parkinson’s patients. L-Dopa can cause Dopa-induced dyskinesia and this has displayed irregularities in handwriting results many times [1] [24].

1.5.3 Age and Senility

Life is constantly changing and with it so does our handwriting. Throughout a lifetime it is thought that a person’s handwriting style will go through four stages. The first stage is the creative phase which is also known as a learning phase. The second is sometimes called ‘the puberty stage.’ also known as the adolescent phase. The third phase is the maturity phase where the style of handwriting stays the most constant for the longest period of time compared to the other three stages. Phase four, or ‘the senility stage,’ is a process in which the handwriting deteriorates. The quality of the handwriting, the smoothness in which it is written and the control the writer has of the pen starts to weaken. This mainly occurs in elderly people. The main changes to handwriting occur in the first stage when the writer is developing their style and also during the last stage as degradation begins. However, it is not just during the last stage that larger changes may occur as certain things that happen in life may influence how a person writes [1] [2].

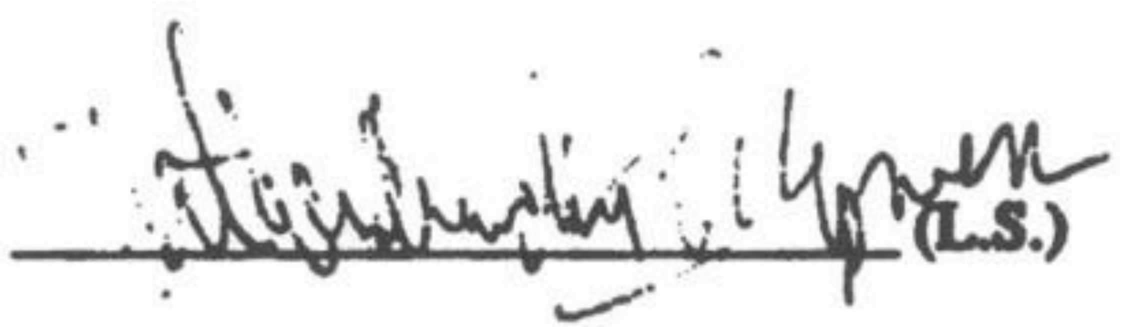


Fig.1.9. Poor line quality and illegible letter forms as a result of an elderly writer [9].

1.5.4 Fatigue or Physical Stress

There are two types of stress: emotional stress and physical stress. Fatigue is the physical form of stress [1] [2]. Huber documented that the results of Nousianen‘s study proved the writing had expanded quite significantly in the horizontal direction due to fatigue [1] [24]. Another study showed an increase in vertical height of lower and upper case letters. Furthermore it has observed that individuals under these circumstances despite of their tendency to increase spelling mistakes and to omit diacritics they mainly maintained habits and overall appearance of their writing [1] [45]. In some circumstances a person may have to sign a document, even if they are suffering from fatigue. However in most cases and especially with more formal documents there is enough time for the person to relax and recover from the fatigue before they have to sign [1] [2].

1.5.5 Alcohol

It is a fact that alcohol is a toxic substance and can poison the body of the consumer in large consumption. Initially this intoxication (or poisoning) may not affect the behaviour of that person. Other people around may not even be aware that there has been alcohol consumed. Drunkenness is not clearly defined but it is a state in which the abilities of the body are weakened or impaired. Drunkenness is more common with higher alcohol intake and therefore higher levels of intoxication [1] [46].

Many researchers investigated the effects of alcohol on handwriting and they all had similar results and therefore reached similar conclusions [1] [47] [48] [49]. As alcohol weakens the body and reactions become impaired, handwriting does also. The blood alcohol content (BAC) at which it is noticeable and the different features of the writing are different in different people. This may be because everybody’s body reacts in different ways to alcohol and their life circumstances are different meaning their state of mind in general can affect the way in which they write. As the BAC increases, the quality of the handwriting decreases. This is shown more in the writing of longer sentences rather than just a signature. As blood alcohol concentration increases the writing gets harder to read because the letters become more distorted, the writing also increases in size horizontally. Shaking is a common characteristic in the writing of people who are ‘chronic drinkers’ or alcoholics [1] [49].

1.5.6 Other Circumstantial Influences

The variation that appears to exist in the writing of one person could increase due to other circumstances. Circumstances under which a written task is executed play an important role in the final appearance of the writing task of each individual and very often can increase the expected range of natural variation from the writer. The increase in natural variation of an individual’s writing is generally accepted, by document examiners, to be due to extreme circumstances. Huber said “Accidental events, caused perhaps by a jolting of the pen or difficulties of control near the bottom of the page, or isolated examples for which there is no apparent reason, can result in a letter being written sufficiently differently from all the others to be outside their range. Such differences should not be taken as evidence of another writer” [1] [2].

One of these occasions is the speed of writing that affects the variations appearing within the writing of one person. Writing can be claimed to have been produced whilst leaning against a wall, whilst travelling in a moving vehicle or on a clipboard held in the other hand. It is understandable to use these excuses plus others such as, confined spaces and no stable support for signing, for poorly executed signature production. There have been many cases in which defence has rested on the poor simulations (extreme conditions) under which questioned signatures were made; however, there is little research to argue against these claims. Normal things which may alter how something is written include: the type of paper and any differences in thickness, the writing implement if different and the surface upon which the writing takes place. For example a sharp pointed pencil will tear paper more frequently when on a softer surface than when on a hard surface e.g. metal. Fibre tip pens, however, can give little evidence away about what kind of surface they were used upon. Some surfaces may have a fine pattern on them; this pattern can be reflected in the writing when the surface is leaned upon to write [1] [2].

The environment in which writing is produced can have an effect on how it appears. For example, a person with impaired vision may find signing in subdued lighting difficult and as a consequence their signature may be affected. Another environmental factor can be temperature. In low temperatures gloves may cause restriction to the fingers and hands. If the fingers and hands are restricted then the movement needed for signing is also restricted, and changes in the fluency of the individual’s signature will occur. In order for the person to sign they may have to use more of their arm, which is not normal for the writer and can cause difficulty in producing more finer movements needed for their signature [1] [2].

When a person is signing a form or a legal document they are more conscious about how they are forming the signature. More care is given to how the signature is written; resulting in a better quality and better visual appearance than it may have done otherwise. There is case evidence supporting these statements [6]. For people who do not regularly sign formal/ legal documentation find the task of doing so, if a time comes when they need to, more important and therefore they will take a more conscious approach to their signature signing [1] [2].

There are other factors that can influence the variation in signatures. These factors could be a signature produced in an uncomfortable position. The signature produced in the normal position of writing at a desk could include extreme differences from a signature made on a postal packet or writing a receipt with the factors of speed, surface or uncomfortable position, having as a result the production of a totally different signature that can then be considered to belong to a different writer. Also, different writing materials can influence the overall appearance of the signature. In the field of questioned document examination it is often asked from the examiners to decide about the authenticity of signatures on different kinds of official documentation forms, most of which have small boxes and limited spaces for the signature [2]. Boxes in which people are to sign in appear on a lot of paper work today, e.g. on some receipts for certain credit cards, tax forms, job application forms and passport forms are a few examples. All of these documents provide a box for the person to sign in i.e. determining the size of the signature. In some occasion the size of the box may affect the formation of the signature. In some other occasions documents are signed under unusual conditions. A document in question could have been signed either standing up and leaning against a wall or leaning down over the document on a desk. The difference in positions may mean there will be differences in the signatures and how the letters are formed and it is possible that these unusual writing conditions will affect the normal appearance. However, it is not well known if constraint changes a signature more than it would change naturally [1] [2] [18].

Document Analysis is a field which was widely accepted to give expert evidence regarding signature and handwriting. Signature examination and identification is routinely carried out by FHEs, the approach to which has been described in numerous text books [1] [2] [5] [11] [18]. Document examiners have specialised knowledge in matters of questioned handwriting and signatures. Past studies [27] [31] have compared FHEs' opinions with those of laypeople and found that FHEs do possess expertise in relation to expressing opinions of authorship of questioned signatures [11]. In addition to this, there are several validation tests for the work of document examiners and studies to prove that their opinion is a lot more accurate compared to that of lay person [50]. The results of these studies help to support the methods that are applied by document examiners and to confirm the expertise of document examiners. However in 1993, the United States Supreme Court ruled that expert testimony admitted in trials (including fingerprinting and handwriting analysis) must be backed by scientific testing of the theories on which the techniques are based, error rates of the techniques, peer reviews of the tests, and acceptability in the relevant scientific community [1] [32].

This controversy to the methods that forensic document examiners apply to arrive at an opinion offers an opportunity to set these techniques on a more scientific basis. For this reason within the last years the field of document examination has a greater interest for statistical studies. The lack of objective measurements causes problems with the reproducibility and persuasiveness of the decisions. It is, therefore, important that traditional methods used in document examination are supported by computerized, semi-automatic, and interactive systems [51]. In a scientific sense techniques that offer objective measurements have significant advantages in any examination. Objective techniques will provide numerical results to questions regarding disputed signatures which until recently were answered with qualitative opinions by the FDEs. Data of this type can be used to develop criteria on which levels of opinion can be expressed [52].

However since the late 1980s' the field is receiving criticism both legally and academically for not providing empirical evidence regarding its claims to expertise. In 1993, the United States Supreme Court ruled that expert testimony admitted in trials (including fingerprinting and handwriting analysis) must be backed by scientific testing of the theories on which the techniques are based, error rates of the techniques, peer reviews of the tests, and acceptability in the relevant scientific community [53].

The National Academy of Sciences of the United States has publically reported ''Strengthening Forensic Science in the United States: A Path Forward'' supporting the view that further studies have to be taken in order to progress various sectors of forensic science. This report expressed the need to provide further studies in all of the aspects of document analysis. Despite the fact that various research appeared to be conducted in regards to the identification of paper and ink still there is a very limited attention and a lack of research into the field of forensic handwriting analysis and especially in relation to how and in what extent intrinsic and extrinsic factors influence handwriting variations [1] [54].

Despite the fact that NAS gives a real value to signature and handwriting analysis there are still strong reservations regarding the ability of the document analysis field to maintain a scientific validity. In any scientific field the only way to achieve validity and reliability is through authoritative and innovative research. This urges the need to undertake research across the spectrum of handwriting analysis which will offer the field of document analysis the prestige and credibility that it deserves according to the long tradition that accompanies the field. Research must be done in the field of electronic engineering regarding computer-based system for handwriting and signature verification in order to follow the NAS guidelines for further studies in all of the aspects of forensic document analysis and especially in the field of forensic handwriting analysis [54].

The courts in the United States show a positive attitude in consideration of the results derived from these computer-based systems in order to evaluate the reliability of the evidence given by Forensic Document Examiner and for the purpose of excluding or admitting this testimony. One of the main challenges that the developers of these software are facing is the fact that they have to present during a legal proceeding in a meaningful way the statistical values that lead to concrete results, regarding the authenticity of an individual's dispute handwriting or a signature, in order to be easily understood by the jury and judge. In addition potential human bias in the use of these systems may be explored and analyzed methodically in a scientific context and in a judicial proceeding. The use of automatic signature verification tools can aid the forensic handwriting experts in drawing their conclusion about the authenticity of a questioned signature, but is not widely accepted nor implemented in most forensic laboratories. However the admissibility of these handwriting verification systems has not been the subject and has not been tested test under judicial rulings [54].

Until we reach the point that the electronic engineering society will develop more robust algorithms and test thoroughly the reliability and accuracy of these systems and also these systems become subject of judicial hearing it is highly recommended not to use these results extracted via a digitizing tablet in respect of the Forensic Document Examiner testimony and parties in a judicial hearing should be very cautious when offering direct evidence derive from these systems. At the present time, having in mind that forensic document examiners examine only static ink traces on the substrate most of the times on paper and due to this significant and valuable dynamic information of the suspect's handwriting, such as velocity, acceleration or stroke duration, is lost to the handwriting examiner we can use dynamic/kinematic features extracted form digitizing tablets in a different way for the benefit of the Forensic Document Examination field. This incident of dynamic data loss can be reduced by developing databases based on the kinematic approach. The kinematic approach involves the development of databases of handwriting and signatures that are collected dynamically by using powerful tools such as digitizing tablets and specialized software. The resulting databases can then be statistically analyzed to determine interactions between writing styles and writing conditions. This valuable information will provide the experts of the field with empirical data that will assist them in their daily work evaluations of kinematic information from static signatures but not to be used directly to support a testimony of an expert witness before a court of law [54].

1.6. Kinematic Methods to Understanding Genuine and Forged Signatures

Before describing how we proceeded in the experiment, it is useful to observe an important difference between static, spatial features of script and dynamic and kinematic aspects. Although we are aware that the practitioner will often have only static samples of a suspected script, it is useful to note that for scientific (and in a more remote sense for practical purposes also) the use of on-line recording techniques of the graphic behaviour of subjects producing either authentic or forged samples of scripts is a necessary condition for the further development of a general theory of handwriting fraud. A specific goal of the present article is to introduce such techniques in the context of a forensic experiment [55].

Forensic document experts examine the static form of signature which is usually in the form of ink trace on paper exactly for this reason very important dynamic information such as signature, cannot be derived from the static form of signature and is lost for the specific [34]. Kinematic method bridges this gap and provide empirical information to specialists for a better understanding of writing and the verification of their methodology and results. Research involving dynamic signatures is carried out under different conditions in order to provide with the necessary empirical information the document examiners. Kinematic methods utilize digital tablets in order to collect the dynamic data. The use of this equipment combined with specialized software such as MovAlyser is possible to obtain dynamic data with speed and accuracy from a written sample. These databases will provide the essential empirical results to forensic document examiners so that they can assess accurately the dynamic information from the static image [6].

When a person write the signature on the tablet the samples of his writing stored on the computer and with the specialized software the analysis of dynamic data is carried out. Using interpolated vertical velocity zero crossing software is able to automatically segment movements made by pen into successive up and down strokes. In kinematic method we are interest in strokes the basic unit of movement which are calculated for the primary and secondary sub movements. Chapter 9 states in his book “The primary sub movement begins where the stroke begins and ends where the vertical velocity changes from decelerating to accelerating for the first time after the velocity peak.

Secondary sub movements are associated with the final adjustments (or “honing in”) and corrective movements”. By this method it is possible for a researcher to collect various dynamic information, the most important and commonly extracted variables are pressure, velocity, acceleration, azimuth, pen –ups and pen-downs [6].

One of the main objectives of this project is to report the differences on signature dynamics by comparing forged and genuine signatures. Dynamic information represents important individual characteristics of an individual’s handwriting which can be of a great effort in discriminating between the authors. Many researches in static and dynamic signatures have provided empirical data in experts to support their work. Mentioning the kinematics method above several researches have been done specifically in this area, so there will be a brief reference to some of these. Simulation signatures characteristics were investigated with the implementation of kinematic analysis techniques [56].

In an investigation van Gemmert and van Galen compared the kinematic characteristics of genuine and forged handwriting. The results of their research showed that the forgers have the ability to successfully copy some of the spatial elements of a handwriting samples such as general acceptance, slope and size. In contrast to these results the analysis of dynamic data obtained by the comparison of genuine and forged handwriting revealed significant differences between these two categories. In forged handwriting observed that were more frequent but smaller force pulses. In addition to this there were longer reaction times and slower speeds in the performance of forged handwriting. In respect of the characteristics pressure significant differences have been also found between the two categories. The recorded pen pressure appeared to be higher in forged handwriting, while in genuine handwriting samples the peak value of pen pressure was higher. Significant limitations of this research, although the first that attempted to examine the dynamics of writing, was the very limited sample size available to make the comparison between forges and genuine handwriting. Moreover their finding are based on handwritten samples executed in a natural way rather than on handwritten signatures. [57]

In a different investigation carried out by Franke between genuine and forged signatures results showed that it could not be a clear distinction between the two categories of signatures taking into consideration the data that it was derived from the comparison of pen pressure, velocity and pen stops of forged and genuine signatures. The author stated that “Only the local, inner ink-trace characteristics as well as variations in ink intensity and line quality can provide reliable information in the forensic analysis of signatures” [51].

Various studies through computer based methods attempted to assess handwritten text for writer identification purposes, analysing the static features the same material that is usually available to forensic document examiners in order to examine a questioned handwritten sample. In addition to this automated handwriting analysis field also implemented dynamic features from inferring dynamic properties and time-sequenced data derived from the static image, providing more information which can be useful in a wider range of situations [58].

In a recent study Franke reported that the complexity of handwritten signatures can affect various global parameters of dynamic information both forged and genuine handwritten samples. Franke made the observation, through her study, that forgers tend to have more pauses (higher value of pen-ups) during the process of signature forgery. However she also reported that higher value of pen-ups also have the individuals whose signatures are of a high level complexity [59].

In another study Franke and Grube presented a method to demonstrate pseudo-dynamic information by evaluating the variations in the density of the ink of the writing trace of an individual. The above method was performed by applying digital image processing algorithms and derived based on forensic experience [60].

In a relevant study Estabrooks reported a method to establish pen pressure from the static image utilizing a confocal laser scanning microscope in order to achieve this notion. The author stated that ‘relative depth values of simulated and traced signatures are similarly measured and are generally found to be clearly distinguishable from genuine signatures’ [61]. Another interesting and innovate study was the method recommended by Spagnolo et al. This study consists of a holographic method that can identifies the author of handwriting samples from the pen pressure exerted on the document during the writing process. A three dimensional image is constructed with the assistant of two laser beans which scan the handwriting sample [62]. In other studies and researchers investigated the signature simulation effects on writing speed parameter. Twelve subjects were asked to copy and trace a historical signature. The whole experiment recorder on graphics tablet and that gave the opportunity to scientists to perform a kinematic analysis on the pressure and speed of writing. The result was that pen pressure has a great variability with speed during non-traced simulations. This research demonstrated that an attempted forgery will affect the execution speed of the genuine signing process and simultaneously the line quality of the genuine signature [63] [64]. Work of Wirotius et al is one of the many studies that dealt with aspects of automatic writer identification. In this research reported another method to assess writing speed and pressure by the evaluation of the pixel levels distribution within an ink line [65].

1.7 Signature Complexity Theory

The scientific community attaches great importance to the validity of the forensic document examiners' opinion and consequently that led to various studies in order to test numerous objective measurements and as a principal goal to implement them in the daily process of examination of document examiners. The need for objective measurement in forensic document examination was the primary motive for the development of complexity theory. Huber stated in his work "The complexity of writing movement is thought to be critical for the reliability of the examination process [2]. Nevertheless the complexity theory is in need of additional research especially in application to real cases. The main objective of this research is to deal specifically with the evaluation of the classification model, suggested by Found et all [7], with new data in order to determine the degree of complexity in a signature under three categories (high, medium, low).

The opinion that there is a great extent of inter writer variation is being adopted by complexity theory. Moreover the theory is based on two basic principles, which are very important for the forensic examination of handwriting and strengthen all expert opinion regarding the authenticity of a handwritten document. First principle is that the more material there is to for the comparison of a disputed writing or signature of a person the easier it is for the expert to reach safer conclusions based on the more differences between genuine and falsified writing there will be more evidential features of forgery in the examination of the disputed writing and signature. To facilitate understanding of this principle we bring as an example the case where a signature contains very few individual characteristics and letters. In this case there is a high probability when examining the signature not shown forgery due to the limited material for comparison [66]. Secondly we find the principle that the more complex the writing of a person, the more difficult it is to be copied by another individual. Due to the fact that the acquired skills of handwriting is an inherent task formed through time for each individual, the result is the forger does not have the natural ability to perfectly replicate the genuine signature. The attempt of the forger becomes even more difficult when the original author has a more complex signature with more features in the formation [66]. As Avni L. Pepe et al. stated “Simulating signatures can be considered a difficult motor task as it involves simultaneous suppressing of one's own motor program while attempting to produce new movement patterns. However, the level of difficulty may vary depending upon the complexity of the signature that is being simulated” [67]. These principles although very helpful in explaining the complexities of a signature is the main drawback is a lack of empirical data to justify their validity. For this reason, in recent years there have been several studies to test the reliability and to determine the validity of these principles. Empirical data in support of complexity theory has been reported [68].

The complexity of the pattern signature until today made by document examiners based on their empirical subjectivity. The handwriting experts must form their opinion on the basis of the static shape signature because in almost all the cases the disputes signatures is om a paper document and not stored in a digitised tablets that can make accurate estimates based on the dynamic data of the signature. The accurate determination and the proper assessment of the complexity of the signature in a case is very important in order to show the court that there is the necessary comparative material for a correct opinion which is interwoven with the difficulty of making a signature. Conclusion of FDEs should be based using the likelihood ratio approach. According to this approach the probabilities to have a similar image between a forged and a genuine signature decrease when a complex signature is under examination. Thus it is expected to have higher changes to detect a forgery in a complex signature. This demonstrates the importance of complexity in the final conclusion in cases of disputed signatures [68].

Several researchers discussed the complexity theory regarding the difficulty of person to execute different types of handwritten tasks. In research made by Wing, he found a relationship between the reaction time (the preparation time that is needed by an individual and the required mental effort to execute a task) and the complexity of writing letters of the alphabet [69]. Subsequently Kao et al also observed an effect between the pressure and complexity. In their research the pressure, performed by the participants when were asked to write on a writing surface, was higher in more complicated tasks regarding the writing [70]. In both cases however the remarkable theory was evaluated in a very general method without detailed justification, taking into account only some parameters (number of strokes or number of letters or curvilinear length of the pattern to draw) and were related to the field of psychology. It would be better that more parameters are taken into account for the evaluation of the theory in recent research.in order to better understand and evaluate if complexity characteristics of a signature change in forged signature cases.

Brault and Plamondon developed an imitation difficulty coefficient, based on the dynamic data of writing in order to determine a person's difficulties to forge a signature. This coefficient can only be applied to biometric signature, which can extract the dynamic information when the author form his signature on an electronic tablet [71].

The field of biometrics is becoming more influential in the way governments and enterprises design the public and private security. A part of biometrics is the comparison of handwritten signatures. Up to date this is a task perform by specially trained personnel capable of recognizing the difference between genuine and forged signatures. Given the technology available today in the field of biometrics the research tested the comparison between people and machines in order to identify the advantages and disadvantages of each category. In this research the aim was to investigate issues such as the complexity and the opinions of authenticity and give some guidelines of the operation of document examiners and machines [72]. They stated “Checking and analysing handwritten signatures as a means of establishing or verifying identity is both a challenge for technology and for the powers of human perception, since there are many situations where signature checking by machine might be inappropriate or, at least at present, insufficiently reliable, for routine use” [72]. They also added that understanding the human skills used by forensic handwriting experts in the evaluation and analysis of a signature will lead to design more appropriate and reliable programs for comparing the disputed signatures. Thus in this research this dealt with complexity theory evaluation. In addition the importance to create a protocol based on complexity theory and other parameters was highlighted, which will bring great benefits to both document examiners and the machines, since it will minimize the margin of error and simultaneously will make the transactions safer [72].

In a state of the art article for automatic signature verification stated that the most common disadvantages of these biometric software appear in the complexity of the signatures. When the signature is small without many features and often similar characteristics and carry less information, it is very likely the system to lead to wrong conclusions [73]. Impedovo and Pirlo suggested for the future in the field of biometrics that there should be a continuous and systematic research on the personalized features not only for the healthy people but also for those with physical and mental disabilities [73]. For this reason it is mentioned that "investigation of the mechanisms underlying handwriting production and the ink-depository processes is worthy of additional attention, as well as studies on feature selection techniques and signature modelling methods for the adaptability and personalization of the verification processes" [73]. These methods will provide valuable information so that they can be used in other areas such as cryptography for a key generation.

Research has shown that the complexity of a signature affect adversely the estimation made by signature verification systems in order to verify the genuineness of a signature. Small and without complicated features signatures have the results of high False Acceptance Rate (FAR) [74]. In addition to this the various changes that are frequent during the formation of a signature of a person, is another factor that leads to wrong estimates. In Alonso-Fernandez et al was stated that there may be a relationship between variability and complexity on the one hand and type and legibility of signature on the other hand. The primary aim of this research was to consider if the combination of these factors can affect the evaluation and the degree of error in off-line signature verification systems [74].

According to FHEs, signature complexity is related to ease of simulation, and therefore to the success of the forging process. The detection of these forgeries is thought to be easier when dealing with more complex signatures (Found & Rogers, 1995) [75]. This theory was also proven to be correct in a research by Sita, Found and Rogers (2002), the results showed that there is an influence when FDEs are called to examine complex signatures [76]. In addition Dewhurst, Found and Rogers had similar results in their study based on real casework evaluations and evidence of agreement in the conclusions of document examiners when dealing with complex signatures [77].

Found and Rogers (1995, 1996, 1998) proposed a complexity theory, which is based on the fact that as the complexity of a signature increases, the likelihood of the potential for a correct opinion increases [75] [78] [79]. They developed a complexity classification model with the aim that one day will be applied in practice to aid the daily work of document examiners and assist their perception in whether a signature is easy or difficult to be forged. The authors in their experiment (1996) asked 13 FHEs to classify in 3 groups signatures in terms of their complexity. [78] These categories would be low, medium and high complexity and were in pursuance of the terms of their empirical asked for this project. In the first category of low complexity the researches asked from the experts to include the signatures that were very simplistic to consider and, in their opinion signatures would be very easy to forge. In the second category should include the signatures with moderate complexity and the experts could have a conclusion. In the third group were the most complex signature that were very difficult to be forged.

These classifications were then related to objectively measurable characteristics of the signatures. The constructed model correctly classified 62.9% of the signatures. These characteristics were taken from the work of Brault and Plamondon [79] with the imitation difficulty coefficient but only 6 out of 10 basic features were chosen and were related to the movement execution parameters of the signatures. Based on a discriminant function analysis, the best predictors appeared to be the number of turning points (TP) and the number of intersections (INTRT). A statistical model with 3 equations were proposed to classify the signatures on a three-point complexity scale based on these objective predictors. The importance of complexity is effectively stated in the following factors as it was mentioned in their research:

“1. As we increase the number of strokes in an image its complexity increases,

2. As the complexity increases, the likelihood of another writer sharing the same elements in the handwriting decreases, and

3. As we increase the complexity of an image, we *decrease the likelihood of that image being* successfully reproduced by another individual.” [78]

In a validation study by the same authors, 72.9% of the complexity scores by 14 FHEs were predicted correctly by the model. For the evaluation of complexity theory Found et al (1998) continued his research work. In this survey asked 14 scientists to put into 3 categories of complexity 300 signatures based on the experience acquired through the daily practice in their profession [78].

Furthermore, Dewhurst, Found and Rogers in another study found that the opinions of specialists were varied and the statistical model managed to correctly classify 83.2% of signatures. [77] This model included in the statistical categorization of the signatures, those of the responses of specialists could be correctly modelled in 75.0% of cases and above were included. Also used only the signatures where more than 3 out of a total of 5 special scientists agree on their classification according to their complexity. so when applied this filter in all a total of signatures we had fairly high percentage of 83.2% in the correct classification of signatures from the statistical model proposed previous in the study by Found et al [7]. Using a sample of 53 real cases, predictions of the statistical model were compared with the opinions of scientific experts to make an assessment of the statistical model and whether it agrees with the opinions of experts. For the reason that was observed a very small percentage of signatures with low complexity to the 53 actual cases examined it was decided to make further investigations on the signatures with low complexity. 566 signatures were collected to determine how many of these are in the category of low complexity. Only 10 out of 566 signatures are found to belong to the category of low complexity. The results of this research despite the fact that it was limited in number indicate that the statistical model predicting the complexity can provide valuable objective results about this issue when examining disputed signatures. This research agrees and simultaneously supports the results of the. Also the data of this research in future can contribute to this sector by offering faster and more reliable results with respect to the complexity of signature [77].

In 2011 in a research of a team with Dutch scientists supported that this method of categorization of the complexity signatures by Found et al [78] although useful is not accurate [68]. This was supported by the fact that three categories are very few to successfully conclude in which of these categories a signature will belong based on its complexity. For example, if two signatures have different measurements but very close to each other, these two signatures are likely to be in a different category based on these results despite of the fact that they are similar. In this experiment four forensic handwriting specialists were asked to classify on a continuous scale 100 signatures in relation to their complexity. The results showed that with the use of objective factors we can predict 69% of the subjective judgments of specialists in relation to the complexity of signatures within this database but putting into practice the model had two major drawbacks. First is not possible to measure accurately the length of the line of a signature because there are several cases where the signature should be formed within the limits of the document which may alter the normal length of the line in a document without limitations. Secondly, although there was an expectation in accordance with the opinion of experts that a legible signature is more easily forged, this study showed the opposite. Legible signatures were more difficult and demand more effort in order to be forged by another person. The researchers concluded that there was an agreement and confirm the model for the complexity of the signatures of Found et al [68] [78].

In another recent research Found and al. proposed a method to examine signature complexity using simulators' gaze behaviour and examine if this investigation would provide support for the theory of Found and Rogers [67] [79]. In order to understand better signature simulation, pupil changes, eye movements and handwriting dynamics were examined when subjects were attempting to simulate two different signatures of different complexities, one of high complexity and one of low complexity according to the criteria of Found and Rogers [78]. Starting point of this research was the theory, that the complexity of a signature affects the effort that an individual have to make in order to produce a good forgery. Furthermore they looked at how complexity influences the views of document examiners regarding the authenticity of a signature. The results showed that there were more fixations with greater duration in the case of forged signatures than the genuine signatures. Also more fixations with greater duration found in the signatures with high complexity. Another interesting result of this research was that there were no differences in fixations between the two different signatures regarding the complexity, when subjects attempted to forge them. Subjects answered questions about which in their opinion was the hardest signature to be forged. The majority of them responded the signature with high complexity, but very few have maintained these opinions with the end of this research. In addition to this more fixation were made in forgery attempts signature with low complexity. Dilation of the iris was more pronounced when people tried to forge signatures with low complexity [67].

The main method used by scientists is the comparative method. Handwriting experts based on the assumption of discernible uniqueness of each signature, study its static and dynamic characteristics in order to decide whether it is genuine or forged. The assumption of uniqueness seems logical but difficult to prove scientifically [79]. In practice the scientists with their experienced critical eye can reach to a conclusion whether a signature is genuine or not, without the degree of complexity of the signature make their decision impossible to make. The intricacy of movement patterns and its relation to the perceived complexity is not well explained in forensic literature. Signature complexity is thought to be a predictor for the ease or difficulty with which a forger can simulate a signature and contributes to the establishment of objective methods to scientifically validate the process of forensic handwriting examination [68]. Further work is needed to find the scientifically accepted manner to confirm complexity theory and introduce this method in the daily work of document examiners in order to consider as a reliable testimony in court supported on acceptable objective criteria.

1.8. Aims and Objectives

The aim of this project is to approach forensic signature examination in a broader way and combine the fields of forensic document analysis, automatic writer identification and evidence law regarding expert witness in relation with biometrics software. This project will assist to increase our understanding of the human handwriting process, especially in relation to forensic document analysis. The study involves kinematic data recorded with a graphics tablet (a computer attachment which can automatically measure pen movements) which will measure the details of how you carry out handwriting tasks. While the vast majority of research on signature authentication has focused on static traces, modern technology has enabled researchers to quantify the kinematic features of signatures at the level of an individual pen stroke. The overall aims are to describe a quantitative approach to the dynamic analysis of signatures and to test a formula proposed by (Found et al.) in order to give a quantitative method for the determination of complexity of a signature.

This research project will attempt to study the levels of difficulty in the simulation of individual characteristics in a signature in order to discover whether any of these characteristics is significantly easier to simulate. Studying the simulation of others' handwriting is as close as we can come to a controlled study of forgery. This study aims to ascertain the role of dynamic inference within the forensic analysis of signatures, as Guest et al. [34] stated “These features can be grouped into two broad categories: static features directly measurable from the writing image (for example slant, letter size, spacing etc.) and inferred dynamic features from the writing image, such as the direction of strokes, pen pressures, pen speeds, fluidity etc. These features must be inferred since the FDE does not typically have direct access to information about how the handwritten fragment was constructed”. [18] In addition an attempt will be made to test the capabilities of given statistical formula to provide us with quantified results regarding the complexity of the signature, so in future it can be included in the methodology of FDEs’ daily work. The last objection of this project is to describe the capabilities of signature verification system and study the legal implementation of quantitative testimony in regards to this sort of software. We believe that there are many potential benefits in seeking to exploit current techniques for automated handwriting analysis in order to place them in the daily work of forensic document examiners.This research will aid in determining the significance of quantitative measurement and the correct application of signature verification system in law.

2. Experimental Design

In this chapter a brief introduction will be presented about what will be included in each of the two studies, there will be a presentation of the database selected and a demographic presentation of the participants.

The aim of Study I was to test the null hypothesis that the 15 selected dynamic and static features (Table 2.1.) do not differ significantly between genuine and forged signatures. This research will aid in determining the significance of forgeries in given cases to establish whether differences can be observed between genuine and forged signatures. In order to investigate the predicted relationship between a forged and a genuine signature the author has to set up experimental conditions, which will be discussed below, in order to compare the performance of the participants who are allocated to one condition or another.

Study II will address the issue regarding complexity of the signatures. A previous research on signature complexity reported the development of a statistical model (Found et al 1996) [7] to predict whether a questioned (or disputed) signature contained sufficient features to express a valid authorship opinion. The aim of study II was to test the predictions of this statistical model with new data and compare these results to the opinions of three qualified FDEs.

2.1. Database used

The signature data within the packages were taken from a subset of the University of Kent's database [80]. The database consists of handwriting samples from 150 individuals. Participants were asked to sign their genuine signature for 15 times, this data was used for the evaluation of complexity formula (study II). In addition they had been asked to choose 3 of the 10 previously registered subjects, who their signatures used as control signatures, and make the attempt to forge their signatures in a "free hand" way. Therefore in forging signatures, test subjects were given unlimited time to practise their forgeries with the original signature available throughout the practice period and forgery donation process [80]. This data was used for the investigation of the levels of difficulty in the simulation of individual characteristics in a signature (study I).

Data for all the signatures was captured by overlaying paper onto the surface of a WACOM Intuos 2 graphics tablet and sampling the pen position and status at 100Hz whilst the subjects performed their signing with an inking Intuos pen. By implement this way of signature capturing process the conditions are becoming identical to conventional signing. Captured data (stored as a series of time stamped pen locations) enabled the analysis of constructional and sequencing aspects of signature production including movements when the pen was not directly in contact with the paper. The paper on which the signatures were drawn was also scanned at a 600dpi, allowing both static and dynamic representations to be captured for each signature sample. As a result both dynamic and static representation can be captured for each writing sample. The project includes two separate sessions. In session 1 participants had to use the normal writing to complete the follow tasks (i) constrained form filling, (ii) bank cheque completion (numeric amount in words and numerals and signature), (iii) free-form signature production and (iv) cursive and block handwriting (copying a passage of text). In session 2 the participants had to simulate the handwriting and signature of one of ten pre-collected target subjects having unlimited time to practice the simulation [80].

2.2 Data selected from database

The subset of the database that will be used in terms of this project is:

1. 2250 genuine samples of individual handwritten signatures (150 participants x 15 signatures. this data was used for the evaluation of complexity formula (study II)

2. 1260 forged signatures (140 participants x 9 genuine sample signatures). The 10th sample genuine signature (see Table 2) was not used by any participant. This data was used for the investigation of the levels of difficulty in the simulation of individual characteristics in a signature (study I) and the evaluation of Cedar software (study III).

3. 150 genuine sample signatures (10 participants x 15 personal signatures).

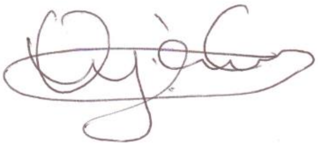
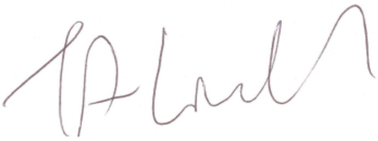
 1st	 2nd
 3rd	 4th
 5th	 6th
 7th	 8th
 9th	 10th

Table 2.1. Signatures used as control samples for forgeries

2.3 Participants

The participants consisted of a mixture of nationalities, gender, handedness and ages. The sample for this project considered as random, i.e. it did not have a specific target group from which to gather the information. Table 2.2 shows the participants' distribution by age, gender, handedness and writing language [80].

Gender • Male writers • Female writers	 39.90% 60.10%
Range of Age • 18-29 • 30-40 • 40-50 • 50-60 • 60-70 • Over 70	 55% 10.50% 6% 10.50% 11.30% 6.70%
Handedness • Right • Left	 91% 9%
Writing Language • English • Western • Non-Western	 81% 8% 11%

Table 2.2. Recap of participants' characteristics

3. Study I - An Investigation of the Levels of Difficulty in the Simulation of Individual Characteristics in a Signature

3.1. Methods and Material

This section will provide the steps followed to perform Study I, in order to make an assessment of the methods chosen and be able to be followed by other investigators in the future.

The final selection of features for analysis was three static and twelve dynamic (see tables 3.1. and 3.2.). These features were chosen because are frequently reported in the literature of automatic handwriting analysis. In addition we believe that the combination of these static and dynamic elements it will be beneficial and is worth to be examined in order to be used in the daily methodology of forensic document examiners in the future. The dynamic features were more numerous than the static, for the purposes of demonstrating the advantages of using the dynamic information extracted from handwritten documents as previously stated and this possibly will help forensic document examiners to write more accurate and comprehensive reports for the courts of law [80]. The following set of static and dynamic features were selected from the University of Kent's database to enable a simulation assessment.

Selected Static Features	Units
1. Width	mm
2. Height	mm
3. Slant	degrees

Table 3.1. Selected Static Features

Selected Dynamic Features	Units
1. Average horizontal velocity dynamic	mm/ms
2. Maximum horizontal velocity	mm/ms
3. Average vertical velocity	mm/ms
4. Maximum vertical velocity	mm/ms
5. Average pen-pressure	levels 0-1023
6. Maximum pen-pressure	levels 0-1023
7. Average azimuth	degrees
8. Maximum azimuth	degrees
9. Average altitude	degrees
10. Maximum altitude	degrees
11. Numbers of Pen-ups	pen-up count
12. Writing duration	ms

Table 3.2. Selected Dynamic Features

3.1.1. Calculation of Features Extracted

Signature Height and Width (Static) – two features containing the height and width of signature in pixels [34] [80].

Slant - Most of the features calculated directly from the digitizer's used and are very straightforward in their definition but slant as feature three on the static features table (table 3.1.) needs some further explanation. Slant is calculated by correcting the baseline to horizontal, extracting the downwards pen strokes from the hand-drawn sample, eliminating the initial and final strokes (being inconsistent with the main slant), and calculating the average angle between the down-strokes and a word baseline. Due to the fact that upstrokes usually connect individual letters, so it is expected to have more variation that the down strokes [80]. Maarse and Thomassen found that the slant of handwriting is determined by the down strokes and noted that down strokes appear to be more stable than upstrokes [81]. Schomaker and Teulings comment that down strokes seem to be the information carriers of handwriting. Thus down strokes are used for slant measurement [82].

Average and Maximum Horizontal Pen Velocity – X and Y (Dynamic) - pen travel velocity (in mm s-1) in the x and y plane. Third order, four coefficient polynomial modelling was used to obtain a derivative of displacement at each coordinate point [80].

Average and Maximum Vertical Pen Velocity – X and Y (Dynamic) - pen travel velocity (in mm s-1) in the x and y plane. Third order, four coefficient polynomial modelling was used to obtain a derivative of displacement at each coordinate point [80].

Writing duration (Dynamic) - the execution time (in milliseconds) to draw the signature [80].

Numbers of Pen-ups (Dynamic) - the number of times the pen was removed from the tablet during the execution time not including the final pen lift at the end of the signature [80].

Average pen-pressure, Maximum pen-pressure, Average azimuth, Maximum azimuth, Average altitude, Maximum altitude - were taken directly from the digitizer [80].

3.1.2. Statistical Analysis

Following the selection of these fifteen features from the database were analysed using statistical model. A Mann-Whitney test was used to test main effects and correlation between genuine and forged signatures for each selected featured. Due to the fact that the residuals were not normal and variances were too different, the results of the normalities tests were negative, so for this reason we had to choose a non-parametric test to check our hypothesis instead of a parametric model such as ANOVA. The Mann-Whitney test should be used for a two condition unrelated design when different subject are used for each of the condition. A separate analysis of the means of these selected features was performed in order to compared and calculated across the two conditions (genuine versus forged) and therefore to discover any significant differences between the means of the fifteen features and to seek for interactions and main effects.

3.1.3. Null Hypothesis

Ho =. Forged signatures (Study I) have no significant effect on the signatures' (static data) signature, Width, Height, Relative Slant or slope of the signature and (dynamic data), Writing Duration, Numbers of Pen-ups, Average horizontal velocity, Maximum horizontal velocity, Average vertical velocity, Maximum vertical velocity, Average pen-pressure, Maximum pen-pressure, Average azimuth, Maximum azimuth, Average altitude, Maximum altitude, compared to the static and dynamic data of original signatures of the writer.

3.2. Results

This section demonstrates the results of the statistical evaluation of the comparison between genuine and forged signatures and the evaluation of signatures complexity. In study I the results attempt to give an answer to which characteristics of the signature are easier to be simulated.

Table 3.3 shows the sums of the mean ranks for the fifteen selected features assessed by a Mann– Whitney U test. The Mann– Whitney U test is the non-parametric equivalent of one-way ANOVA, which analyses the significance of differences in the median values of ranked data. It is a distribution free test in that it makes no assumption about the data being normally distributed. In this case the sample groups are Velocity, Pressure, Altitude, Azimuth, Number of Pen-ups, Writing duration, Slant, Width, Height of the simulated signatures. Table 3.3 shows results of the Mann– Whitney U test on the difference in comparison of pairs (genuine versus forged signatures) of the used variables. For all the pairs the differences are significant beyond the 0.05 level.

Results of statistic test	Average Horizontal Velocity	Maximum Horizontal Velocity	Average Vertical Velocity	Maximum Vertical Velocity
Mann-Whitney U	22135.000	58965.500	82407.000	49079.500
Wilcoxon W	739138.000	775968.500	799410.000	766082.500
Z	-15.061	-6.860	-1.641	-9.062
Asymp. Sig. (2-tailed)	.000	.000	.101	.000
Results of statistic test	**Average Pressure**	**Maximum Pressure**	**Average Altitude**	**Maximum Altitude**
Mann-Whitney U	46887.500	66541.500	68109.000	62911.500
Wilcoxon W	58212.500	77866.500	785112.000	779914.500
Z	-9.550	-6.198	-4.824	-5.991
Asymp. Sig. (2-tailed)	.000	.000	.000	.000
Results of statistic test	**Average Azimuth**	**Maximum Azimuth**	**Number of Pen-ups**	**Writing Duration**
Mann-Whitney U	72288.000	70223.500	83109.000	16927.500
Wilcoxon W	83613.000	81548.500	94434.000	28252.500
Z	-3.894	-4.354	-1.493	-16.221
Asymp. Sig. (2-tailed)	.000	.000	.135	.000
Results of statistic test	**Slant**	**Width**	**Height**	
Mann-Whitney U	83756.000	87253.500	79130.000	
Wilcoxon W	95081.000	804256.500	796133.000	
Z	-1.340	-.561	-2.370	
Asymp. Sig. (2-tailed)	.180	.574	.018	

Table 3.3. Results of project for Mann-Whitney test – Study I (with grey shade parameters statistically significant)

3.2.1. Velocity

The statistical analysis results for the comparison of velocity for condition genuine and forged in signatures are shown in Figures 3.1 and 3.2. Genuine signatures were found to have increased velocity of execution of signature in relation to forged signatures in three out of four conditions examined. The effect of forged signatures were statistically significant in the occasions of Average Horizontal Velocity (U(1408) = 22135, p=.000, sig≤.05, 2-tailed)) with the genuine signatures to be 75.05% higher than the forged signatures 2.06 versus for 0.72 mm/ms. Maximum Horizontal Velocity (U(1408) = 58965, p=.000, sig≤.05, 2-tailed)) with genuine be written faster 28.50% than forged signatures at this parameter (43.80 versus .31.32 mm/ms,) and finally Maximum Vertical Velocity (U(1408) = 49079.5, p=.000, sig≤.05, 2-tailed)) with genuine signatures to outweigh the forgeries with 27.98% in this parameter (15.80 vs 11.38 mm/ms) However, the effect of Average Vertical Velocity was not statistically significant (U(1408) = 82407, p=.000, sig≥05, 2-tailed)).

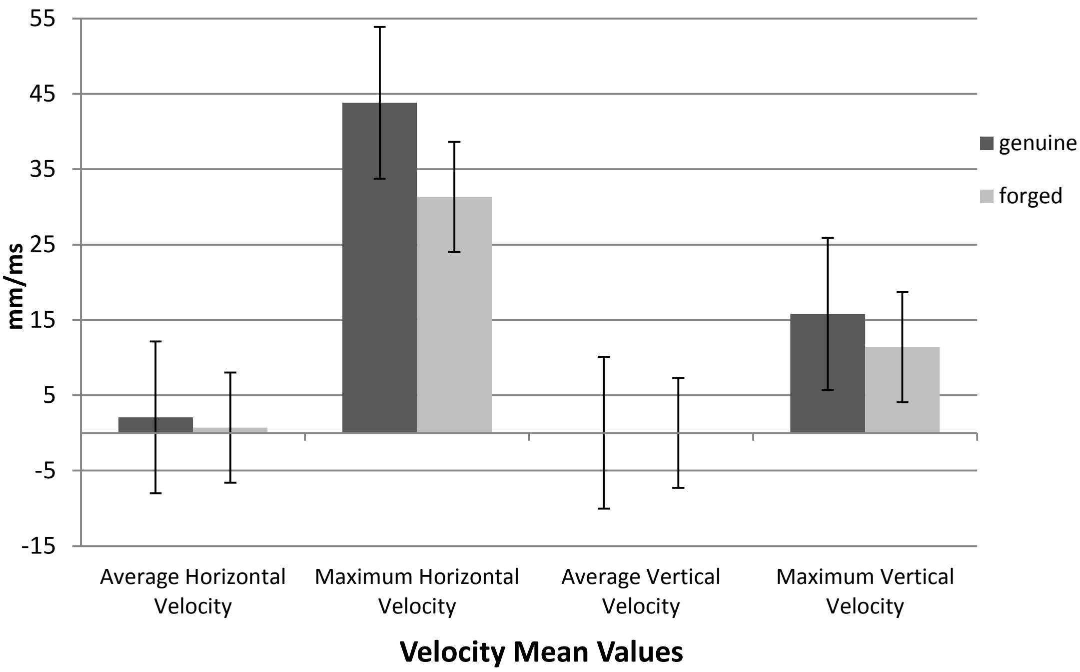


Fig.3.1. Comparison of Velocity Mean Values

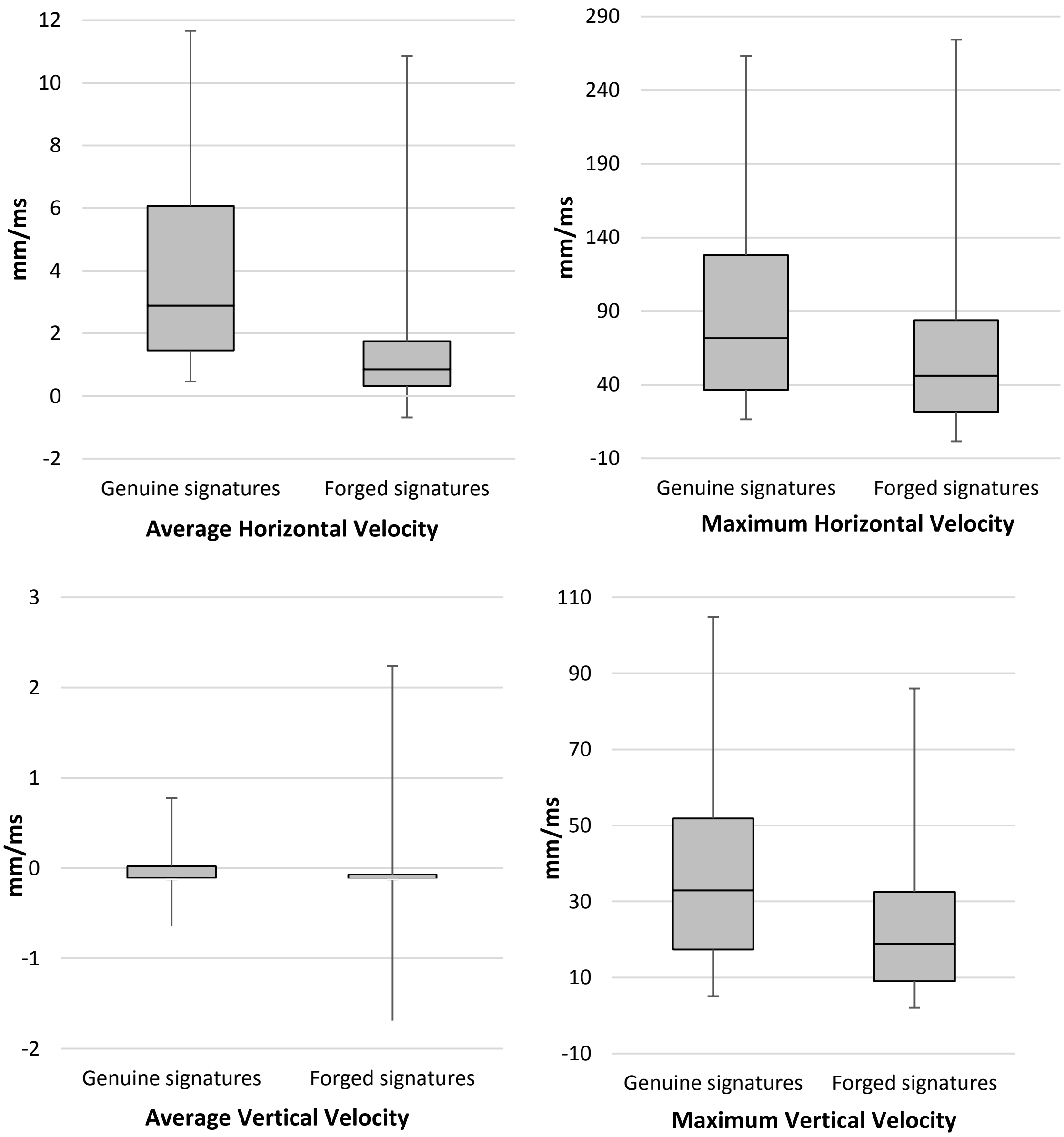


Fig.:3.2. Boxplots expressing the differences between forged and genuine signatures for Velocity variable

3.2.1. Pressure

The results for pressure variables are shown in Figure 3.3 and 3.4. We found a significant effect for both Average Pressure (U(1408) = 46887.5, p=.000, sig≤.05, 2-tailed)), and Maximum Pressure (U(1408) = 66541.5, p=.000, sig≤.05, 2-tailed)) comparing genuine with forged signatures. However the effects of this interaction vary. Although there was a significant effect for both variables (Average Pressure and Maximum Pressure) forged signatures were written with greater maximum pen pressure than the genuine signatures during the formation of the signature. In addition genuine signatures were written with significant less average pen pressure used in comparison with forged signatures. Average pressure in genuine signatures was found to have 866.18 (levels of pressure 0-1023) against 745.91 (levels of pressure 0-1023) which means that forged signatures had 13.89% higher average pressure value than the genuine signature. Moreover the maximum pressure of forged signatures was 3.7% higher than the maximum pressure of genuine signatures (981.31 versus 945.40) (levels of pressure 0-1023).

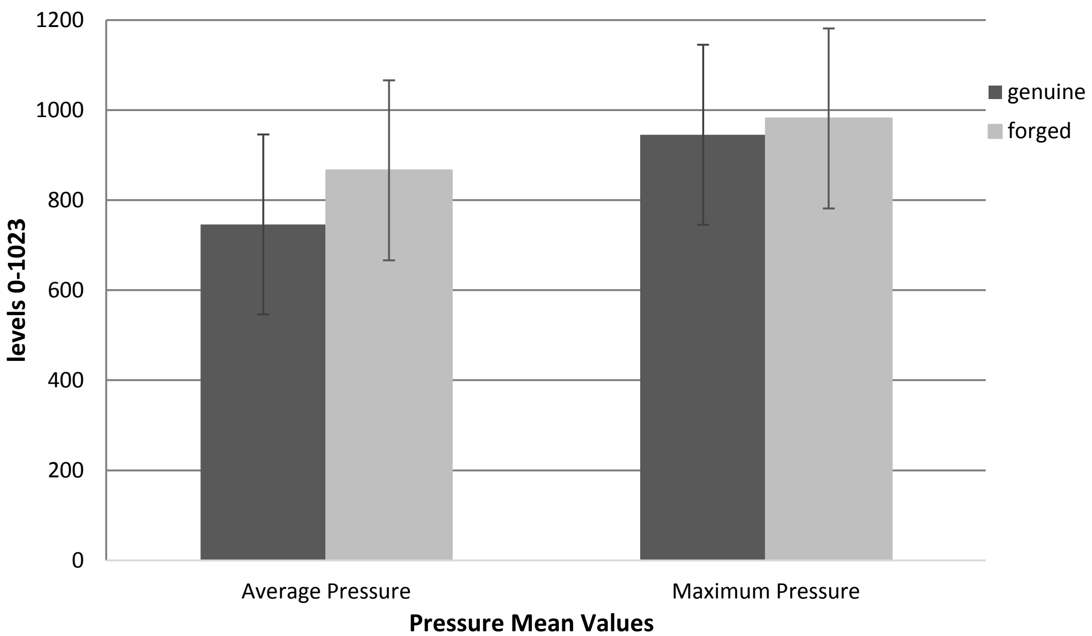


Fig.3.3. Comparison of Pressure Mean Values

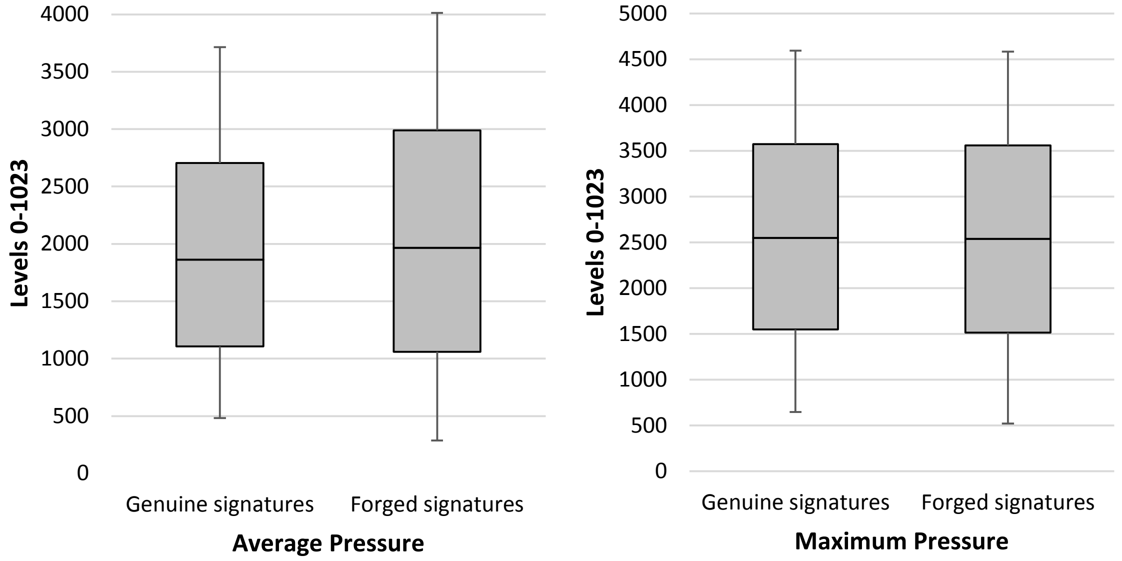


Fig.3.4. Boxplots expressing the differences between forged and genuine signatures for Pressure variable

3.2.2. Altitude and Azimuth

As with average and maximum pressure we found significant effects for all four variables tested here. Average Altitude (U(1408) = 68109, p=.000, sig≤.05, 2-tailed)) genuine was 3.29% higher than forged signatures (569.4 vs 550.75 degrees), Maximum Altitude (U(1408) = 62911.5, p=.000, sig≤.05, 2-tailed)) here again genuine was 5.33% higher than forged signatures (626.8 vs 593.4 degrees).as it concerns the factors regarding azimuth there was a significant difference for both parameters between forged and genuine signatures. Average Azimuth (U(1408) = 72288, p=.000, sig≤.05, 2-tailed)) but in this case forged signatures were higher than genuine with 10.80% (1291.8 vs 1448.2 degrees), Maximum Azimuth (U(1408) = 70223.5, p=.000, sig≤.05, 2-tailed)). Again here forged were 10.31% higher than genuine in this parameter (1409.9 vs

1571.8). Forged signatures had less angle degrees in both altitude variables observed, compared to genuine signatures. In contrast average and maximum azimuth were found to have more angle degrees in forged signatures in comparison with genuine signatures. The results for altitude and azimuth are shown in Figures 3.5 and 3.6.

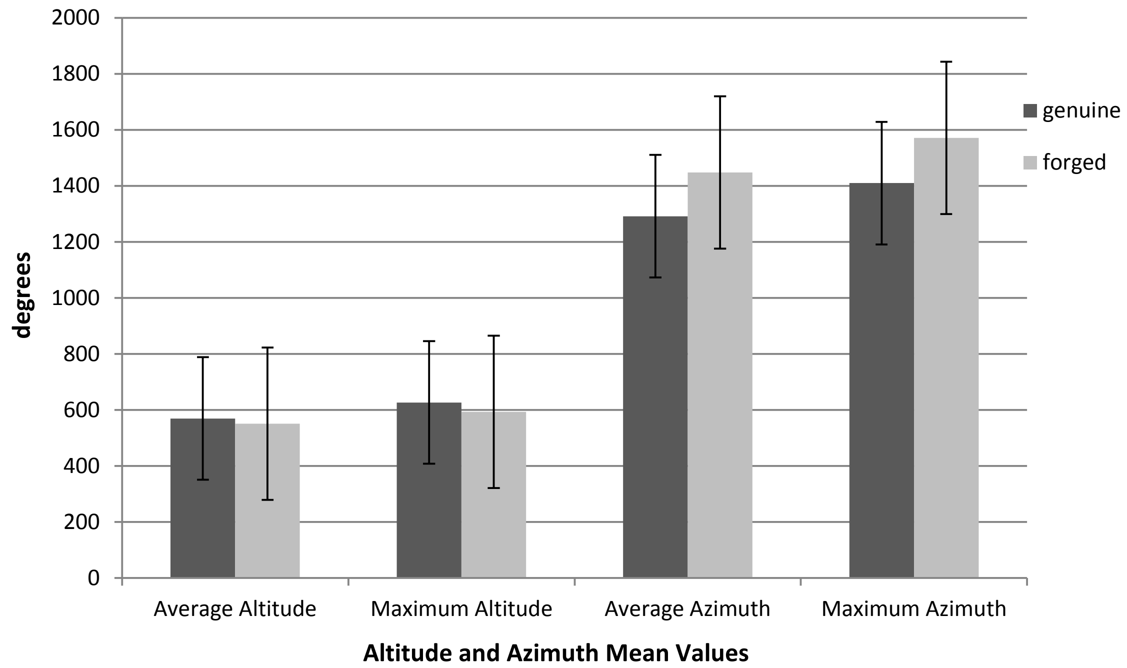


Fig.3.5. Comparison of Altitude and Azimuth Mean Values

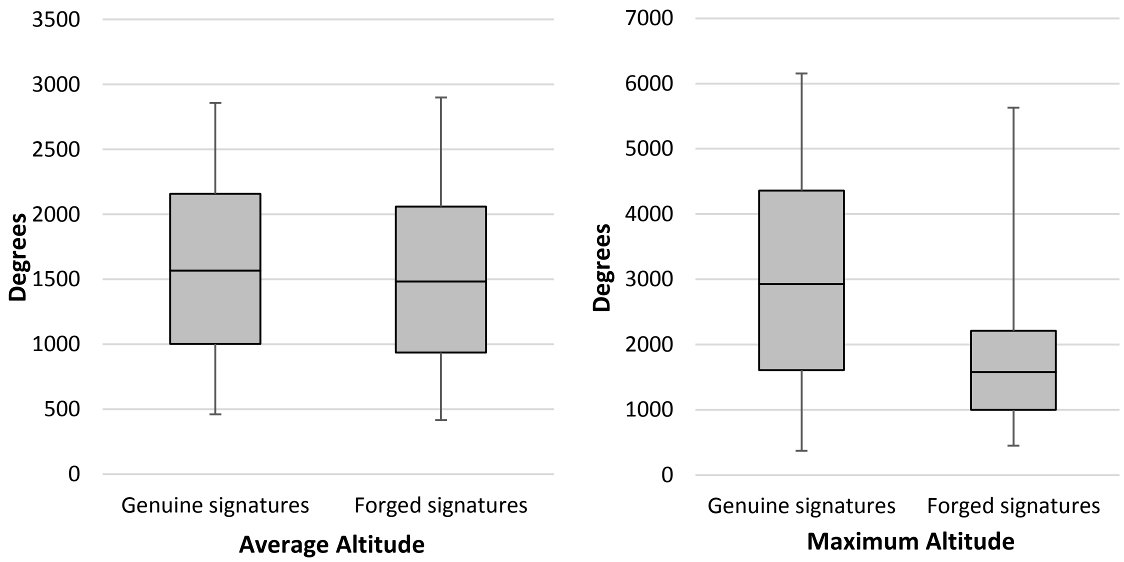


Fig.3.6. Boxplots expressing the differences between forged and genuine signatures for Altitude and Azimuth variables (Continued next page)

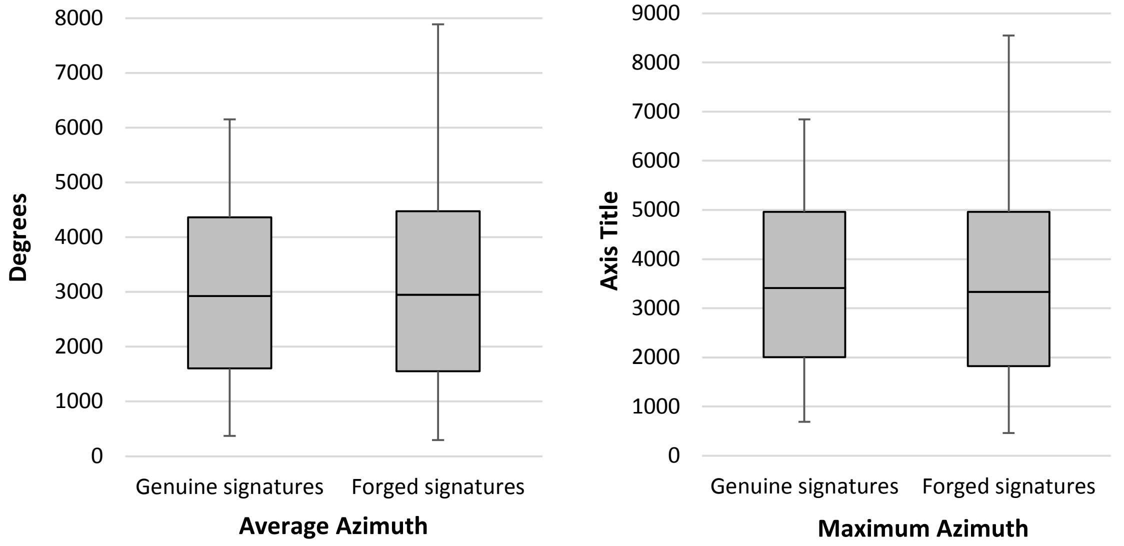


Fig.3.6. Boxplots expressing the differences between forged and genuine signatures for Altitude and Azimuth variables

3.2.3. Width and Height

The results for Width and Height are shown in Figures 3.7 and 3.8. No significant differences were found between forged and genuine signatures when compared for Width variable. We have not found any significant main effect neither for width (U(1408) = 87253.5, p=.574., sig≥05, 2-tailed)). In contrast in height parameter was a significant effect (U(1408) =,79130, p=.018, sig≥.05, 2-tailed)) and genuine signature had a higher value of mm in comparison with forged with 4.92% difference (1241 and 1180 mm As you can observed form the Figures 3.7 and 3.8.

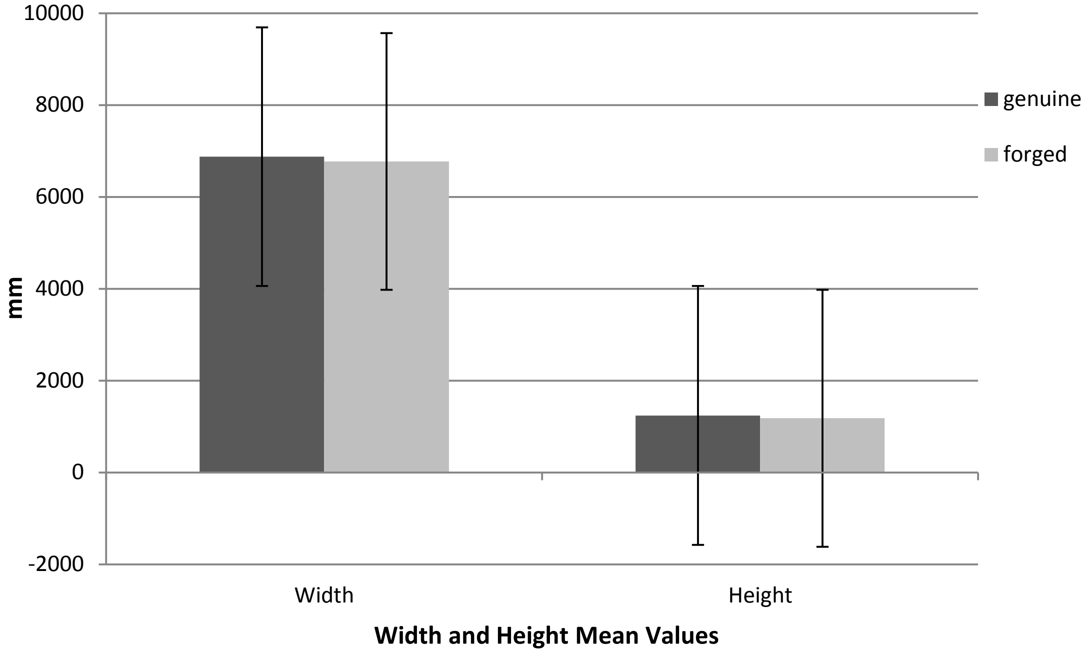


Fig.3.7. Comparison of Width and Height Mean Values

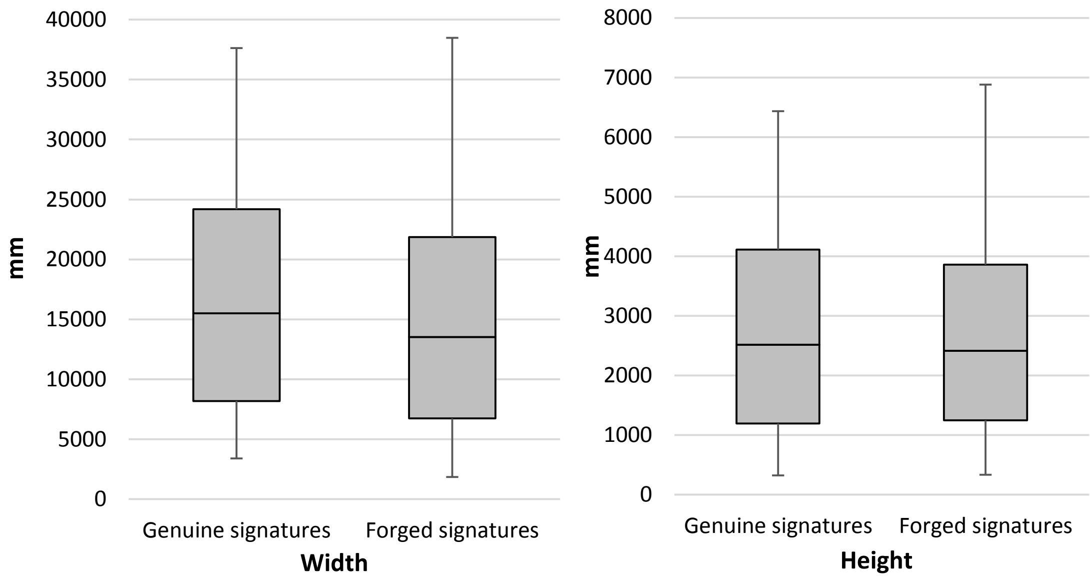


Fig.:3.8. Boxplots expressing the differences between forged and genuine signatures for Width and Height variables

3.2.4. Writing Duration, Slant, No of Pen-ups.

The results for these variables are shown in Figures 3.9-3.12. We found a significant main effect for writing duration (U(1408) =16927.5, p=.574., sig≥05, 2-tailed)) a significant for this result for this project it was the fact that forged signatures writing duration was far greater than genuine signatures. This parameter was one of the most important in this study because they two signature categories had one of the greatest differences between them from all the comparisons made for this study. The result for genuine signatures writing duration was significant lower 78% (3205.5 vs 14594.9 mm) than this of forged signatures (Figure 3.11.). On the other hand we have not found any significant main effect for slant (U(1408) = 83756, p=.180., sig≤05, 2-tailed)) (Figure 3.9.) where in this variable were not occurred any significant changes presented between forged and genuine signatures. No such significant effect found in pen-ups variable also (U(1408) = 83109, p=.135., sig≥05, 2-tailed). As it is easily seen from Figure 3.10 the differences between forged and genuine signatures are not significant and the results of the comparison are similar.

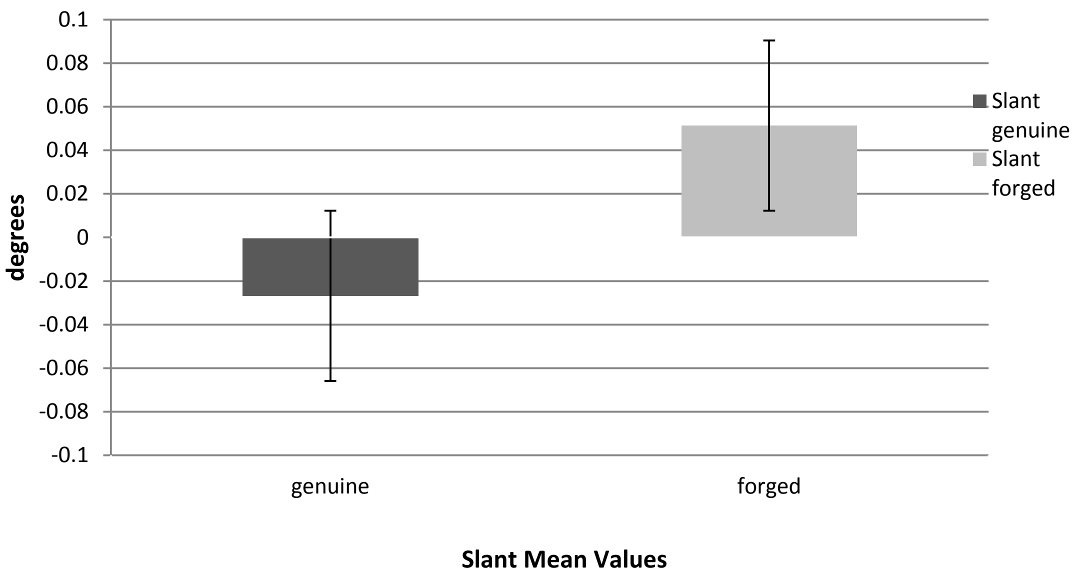


Fig.3.9. Comparison of Slant Mean Values

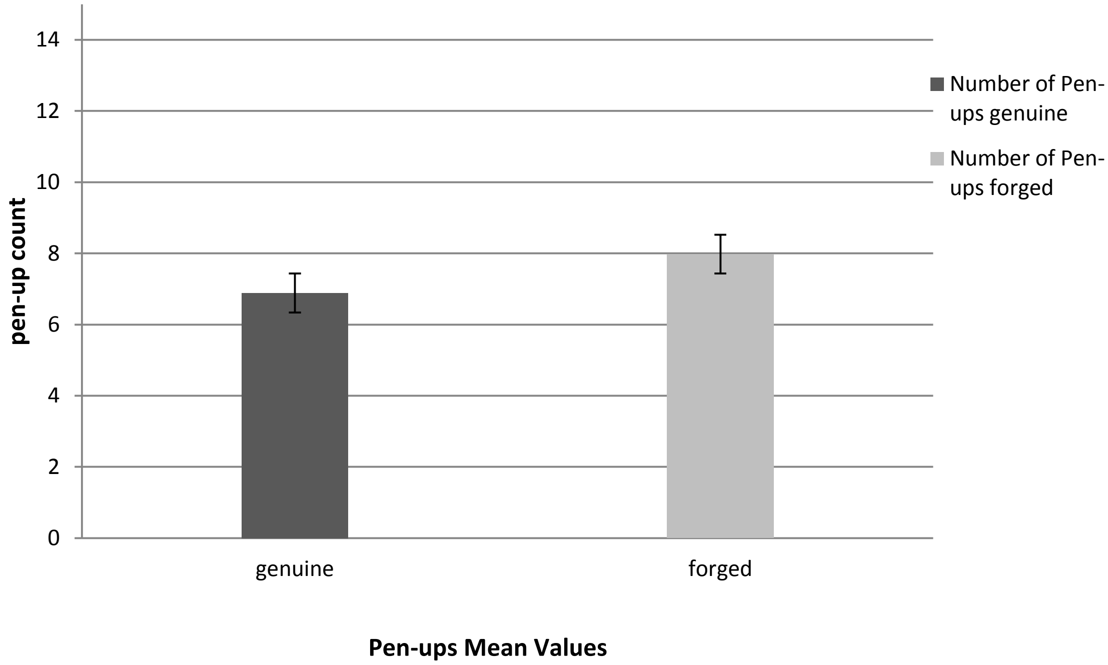


Fig.3.10. Comparison of Pen-ups Mean Values

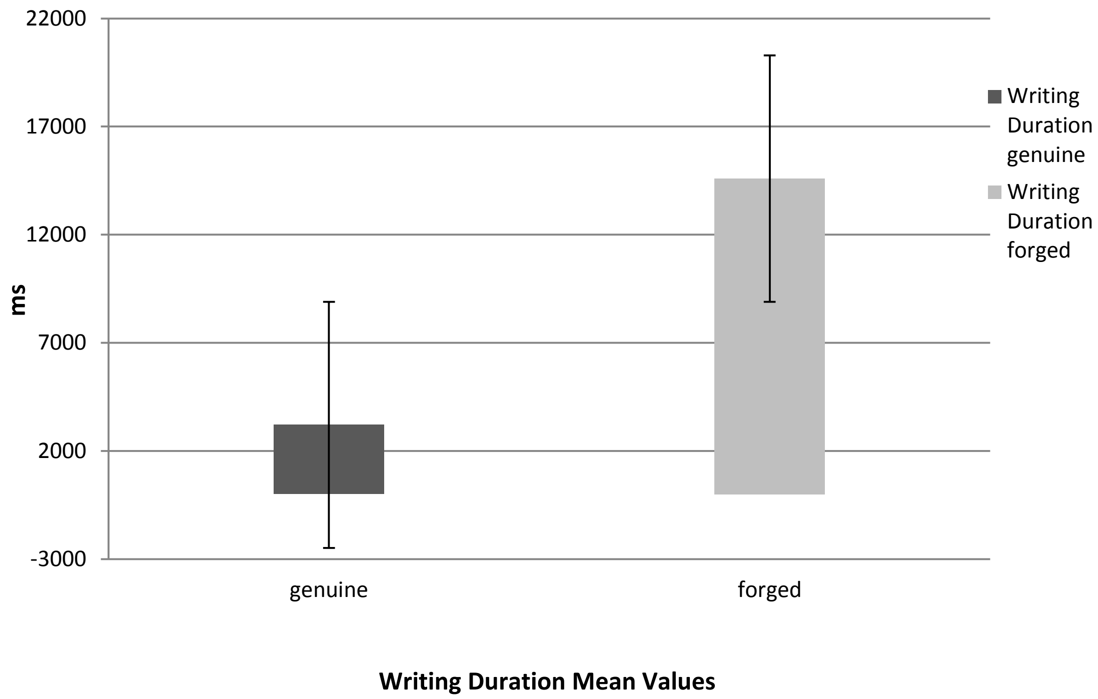


Fig.3.11. Comparison of Writing Duration Mean Values

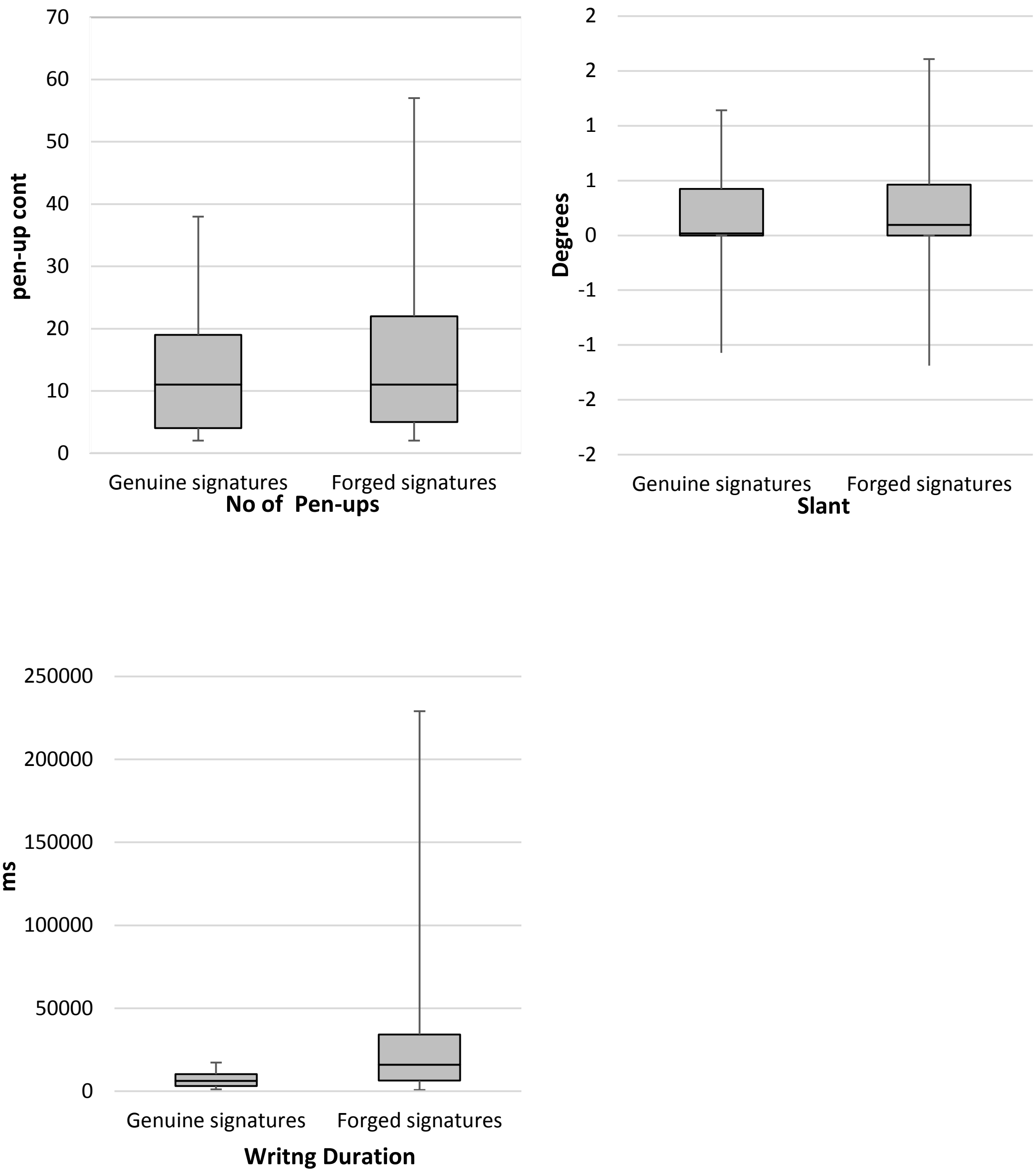


Fig.3.12. Boxplots expressing the differences between forged and genuine signatures No of Pen-ups, Slant, Writing Duration variables

4. Study II – Evaluation of Complexity Formula (Found & Rogers 1996)

4.1 Methods and material

This section will provide the steps followed to perform Study II, in order to make an assessment of the methods chosen and be able to be followed by other investigators in the future.

Using the 150 genuine signatures without constrictions of the first session of our database an evaluation of the complexity formula suggested in Found et al will take place. In their work the best predictors appeared to be the number of turning points (TP) and the number of intersections (INTRT) so for this reason these will be the parameters that will be measured in this project. The number of turning points (TP) and the number of intersections (INTRT) will count in a subjectively way by the author using the guidance given in the work of [7]. Equations were proposed to classify the signatures on a three-point complexity scale based on these predictors. A visual explanation of how these equations used can be found on table 4.1 and figures 4.3.-4.5.

Categories	Formula Equations
CAT-1 represents High Complexity	**CAT-1** = 0.341 TP + 0.240 INTRT - 9.418
CAT-2 represents Medium Complexity	**CAT-2** = 0.169 TP + 0.087 INTRT - 2.915
CAT-3 represents	**CAT-3** = 0.099 TP - 0.026 INTRT - 1.508

Table 4.1. Categories of signature complexity and formula equations

4.1.1. The Number of Turning Points (TP) in the Line

This experiment aimed to follow as closely as it could the work of (Found et al.) in order to find out if the proposed formula can be applied to other signature cases by using the naked eye of the investigator. TP was determined according to the following criteria. The starting point and terminating point of any continuous line trace was counted as one point each. To count the major turning points along the line, a small pointer was used to follow the trajectory of the line according to the sequence of formation. Whenever the line of signature change direction, that point was counted as one (. The total score was the sum of starting and terminating points and the number of points counted along the line. Diacritic marks were excluded from the counting process [7]. (See figure.4.1.).

4.1.2. The Number of Line Intersections Including Retraced Line Sections (INTRT)

To calculate INTRT, the trajectory of the line trace in the direction of formation was followed. The number of times where the line either intersected with, or retraced over, previously formed sections were counted [7]. (See figure.4.2.).

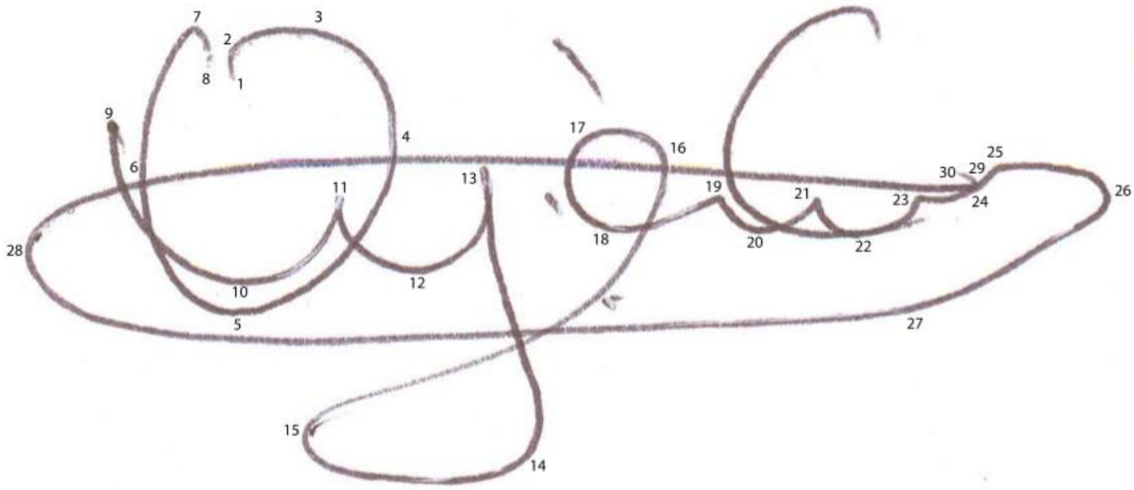


Figure 4.1. Example of a signature illustrating the numbered turning points (JP) associated with the signature.

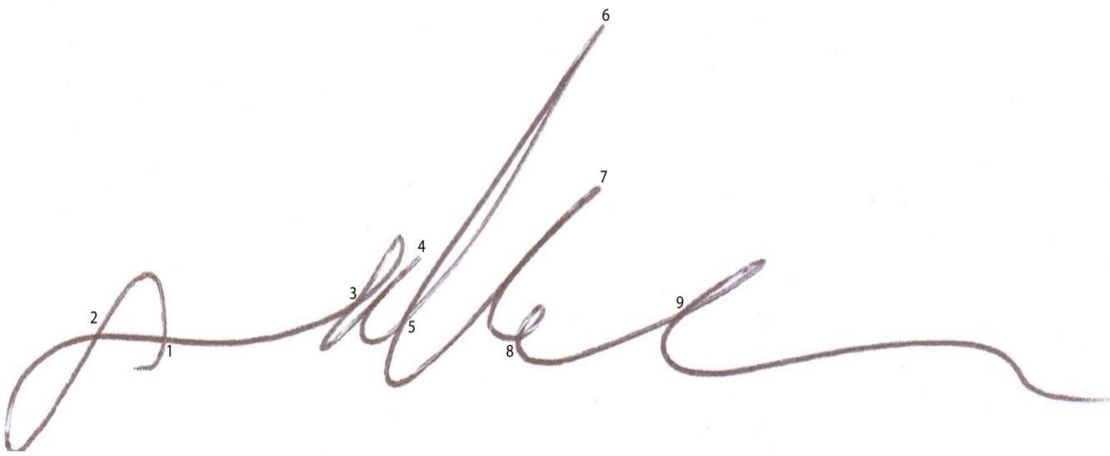


Figure 4.2. Example of a signature illustrating the numbered intersections and retraces (INTRT) associated with the signature.

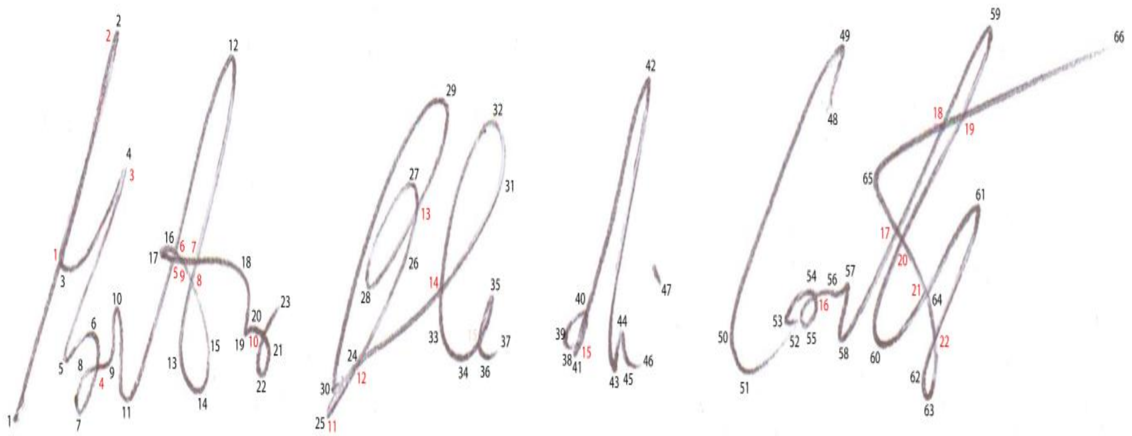


Figure 4.3. Example of group 1 signature.

Turning Points (Numbered Black Colour) =66

Intersections and Retraces (Numbered Red Colour) =19

gl = 17.6276498

g2 = 9.86238616

g3 = 4.49995646

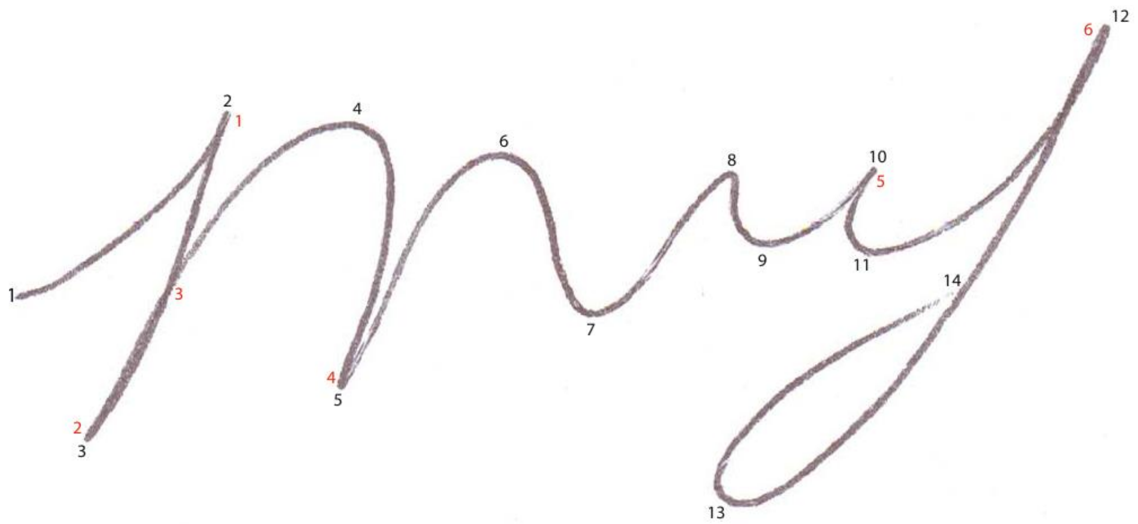


Figure 4.4. Example of group 2 signature.

Turning Points (Numbered Black Colour) =14

Intersections and Retraces (Numbered Red Colour) =6

g1 = - -3.2089218

g2 = 0.14120392

g3 = -0.33837362

Figure 4.5. Example of group 3 signature.

Turning Points (Numbered Black Colour) =6

Intersections and Retraces (Numbered Red Colour) =1

g1 = -7.1336734

g2 = -1.81684856

g3 = --0.9427243

4.1.3. Task for Forensic Document Examiners

Using the signatures without constraints from the Kent database, static images were sent to three leading professional forensic document examiners employed by Key Forensics in the UK. These experienced forensic document examiners gain great expertise over many years through a wide variety of cases investigations cases in regards to disputed signatures and they have been invited to testify at different national and international courts. 150 signature sample images were arranged on a form divided into four signatures per page reproduced at normal size. Below each signature were three options for complexity assessment: High, Medium or Low (see Figure 4.6.). Each forensic handwriting examiners analysed the signatures independently drawing on their individual expertise and experience. In addition, at the end of the document, the FDE were also asked to describe briefly the major factors that led them to select one of the three signature complexity level.

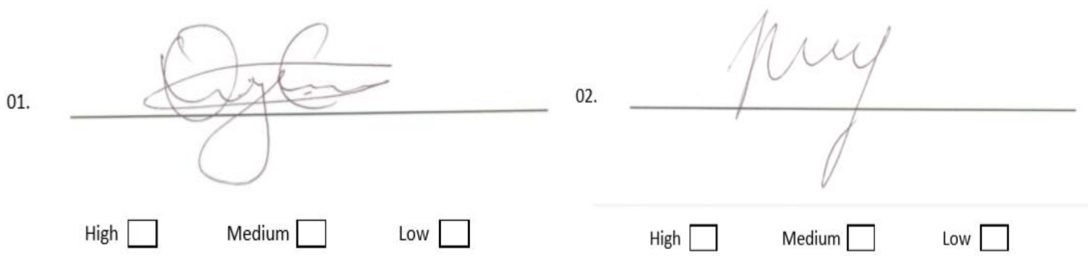


Figure 4.6. Sample signature form for FDEs

4.2 Results

This section demonstrates the results of the second study which deals with the evaluation of complexity formula suggested by Found et al. [7] based on new data and make a comparison between the outcome of this statistical formula and the FDEs' opinion about the complexity of the signatures given, based on their expertise and experience.

Of the 150 signatures included in this dataset and used for study II, four were classified by the model as Group 1 signatures (3%), forty five were classified as Group 2 signatures (30%) and one hundred one signatures were classified as Group 3 signatures (67%). The simplest signatures recorder in this dataset was found to have 7 TP and 1 INTRT (group 1). In contrast the signature with the highest complexity scores was found to have 123 TP and 33 INTRT. Clearly, the value of the objective complexity classification was in indicating whether a signature was too simplistic to base an authorship opinion on or whether the signature contained sufficient features such that an authorship opinion (either qualified or unqualified) could be expressed.

The three FDEs agreed on 93 of the signatures (61%) whilst in the remaining 57 signatures, at least two of them agree (39%). In this study we did not record any case in which forensic document examiners gave three different answers one from each expert for the evaluation of signature complexity (see Fig. 4.7). Within these 57 signatures, in 28 cases there was a disagreement between assigning a signature to be low or medium complexity. In other 29 cases the disagreement was between considering medium or high complex. The main reason for the differences in their opinions is the fact that three categories are very few to successfully conclude in which of these categories a signature will belong based on its complexity. For example, if two signatures have different measurements but very close to each other, these two signatures are likely to be in a different category based on these results despite of the fact that they are similar.

The statistical model agreed on 80 of the signatures (53%) with the FDEs' opinions having even one same answer with them. In 25 signatures the statistical model had only one same answer with one out of three of the FDEs (17%), the percentage was slightly lower (13%) in the case that the statistical model agreed with two out of three FDEs in 19 signatures. The highest percentage (24%) found on the third classification where the statistical model agreed with all the three FDE in 36 signatures. On the other hand the statistical model failed to agree with none of the FDEs and had wrong results in 70 signatures (47%) for these results see in Figure 4.8 below. A comparative view of all the results of the FDEs' opinions together with the results of the statistical model can be seen in Figure 4.9 below.

The main factors indicated by the FDEs when assigning high signature complexity was: i) the existence of multiple pen strokes and whether they overlap or not, ii) the existence of multiple changes in directions, iii) length, iv) the difficult to determine the path of strokes sequence followed by the signers and v) the degree of signature illegibility. If a signature was short with a simple structure and clean path it was considered of low complexity. The signature which weren't considered low or high complex would fall consequently in the medium complexity level. FDEs based their assessment mainly on static features extracted from the signature image. A number of techniques allow FDEs to extract or estimate dynamic information such pressure or velocity. However, due to the time required for the task of assessing 150 complexity signatures, these techniques were not applied by the FDEs.

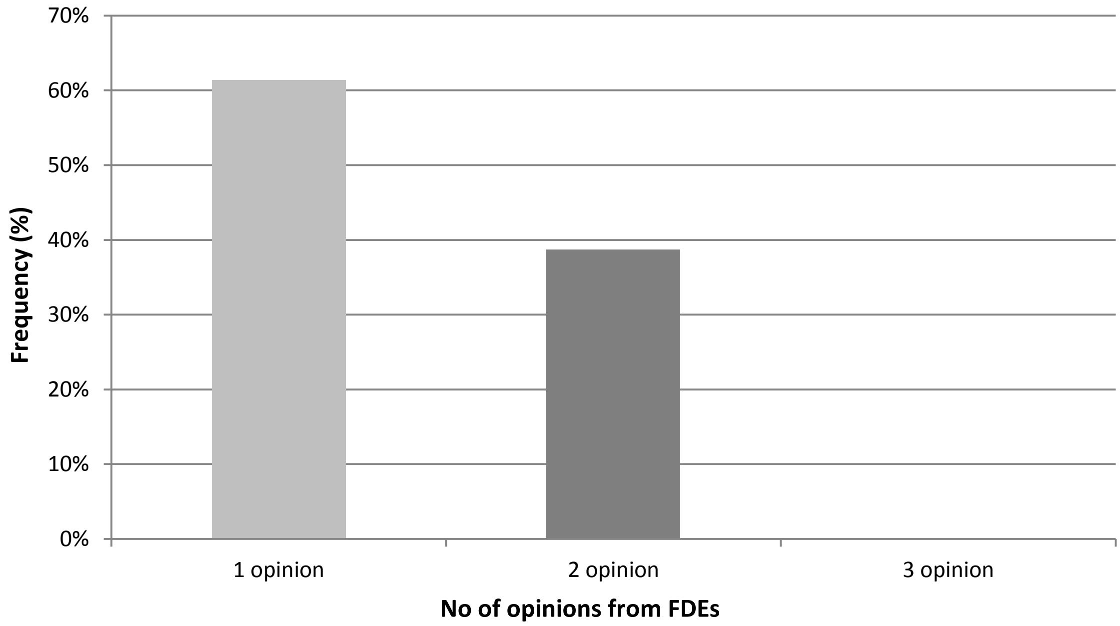


Fig.4.7. Number of similar opinions from FDEs overall for all signatures tested for complexity evaluation

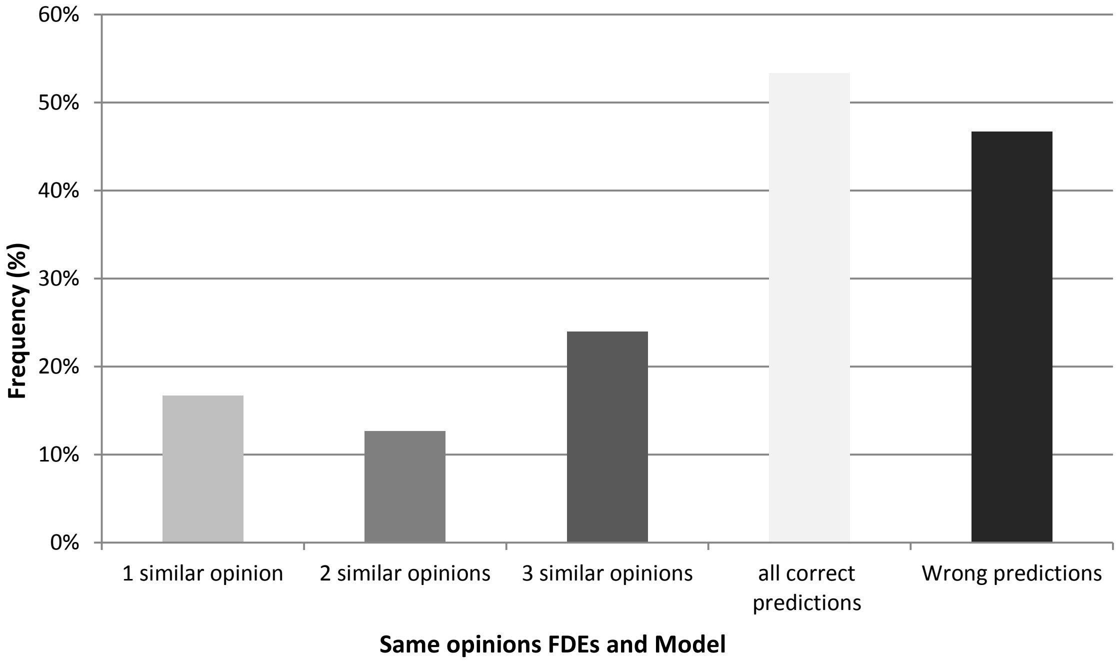


Fig.4.8. Number of same opinions for FDEs and overall correct and fault predictions for model regarding signatures complexity.

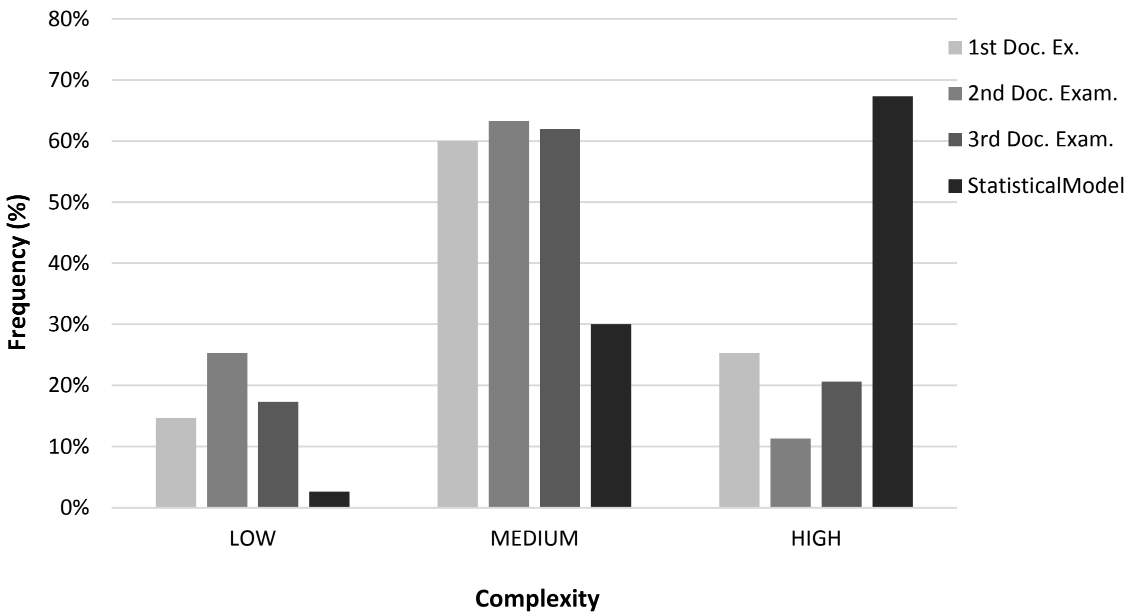


Fig.4.9. Signature complexity histograms from the three FDE and the statistical model

5. Discussion of Studies I and II

Study I investigated whether there is any relationship between the conditions of forgery and genuineness in signatures. The present study contributes to the understanding of important differences in the production of genuine versus forged signatures. The findings supported previous literature showing differences between genuine and forged signatures along several kinematic parameters. In addition the aim of Study II was to test the predictions of this statistical model with new data and compare these results to the opinions of three qualified FDEs.

5.1. Study I

We hypothesized that handwriting kinematics would differ across these two conditions and that these differences would be present in all the fifteen kinematic parameters which were included in this study. For study I it was used a fifteen-parameter kinematic model, genuine signatures were distinguished from forged signatures with greater than 73% accuracy (11 out of 15 parameters measured). There is ample evidence that high quality forgeries are possible after training. However, a closer view of the kinematics of the forging writers is responsible for our main conclusion, that forged signatures are widely different from genuine especially in the kinematic domain. We found that some, but not all, parameters differed between the different signature styles. The 11 parameters out of 15 experienced significant changes when the two comparison of the two groups (genuine versus forged signature) took place and give a clear picture of which parameters can assist forensic document examiners and can be used by them to examine the signatures forgeries.

Specifically, for Study I, we found that the parameters that assist FDEs as an important discriminator between genuine and both forged signatures were Average Horizontal Velocity, Maximum Horizontal Velocity, Maximum Vertical Velocity, Average Pressure, Maximum Pressure, Average Altitude, Maximum Altitude, Average Azimuth, Maximum Azimuth, Height and Writing Duration. Table (3.1, page) shows the general results for all statistical tests that allow us to have a comparative picture of all the tests in their entirety However, the genuine and forged signatures could not be separated by five parameters which are Average Vertical, Velocity Slant, Width Height, and Number of Pen-ups.

Therefore, FDEs could reliably reach their conclusion based on the 11 parameters mentioned above. In addition to this forged and genuine signatures could be distinguished better taking into consideration the parameters that had the more significant differences between them. This indicates that FDEs have a better chance of discriminating between genuine and forged signature using the parameters of velocity, pressure. This supported by the fact that the greater differences between the genuine and forged signatures were detected in the categories that are directly associated with these two parameters. The 5 parameters that found to indicate the most significant difference between forged and genuine signatures were Average Horizontal Velocity with the genuine signatures to be 75.05% higher than the forged signatures, Maximum Horizontal Velocity with genuine to have higher result 28.50% than forged signatures at this parameter, Maximum Vertical Velocity (U(1408) = 49079.5, p=.000, sig≤.05, 2-tailed)) with genuine signatures to outweigh the forgeries with 27.98% in this parameter, Average pressure in genuine signatures showed that forged signatures had 13.89% higher average pressure value than the genuine signature and finally Writing Duration where the result for genuine signatures writing duration was significant lower 78% (3205.5 vs 14594.9 mm) than this of forged signatures. The other 6 parameters that found to have a significant effect in the relation between forged and genuine signatures, the comparison of the mean values revealed that the difference between the two groups was less than 10% for all the parameters that were included in this study except Maximum Azimuth that it was slightly above 10%.

Genuine signatures were written with less average pen pressure forged signatures. It might be expected that a writer would apply more pressure when forging a signature due to the fact that he/she will be more careful to shape as better as he/she can the overall appearance of the signature in order to resemble with the genuine signature. This is in agreement with previous studies that found that “generally speaking, the overall pressure patterns of a writer’s signature have been shown to be habitual and highly individualistic to that writer” [61] and that “dynamic pressure patterns are an integral part of an individual’s signature” [83].

The other parameters that considered to be very important for the investigation of a forged signature are velocity and writing duration which is directly linked to the line quality of the signature. In the present study all statistical analyses unequivocally showed that forged signatures result in longer reaction times and are produced at a slower rate. As it mentioned earlier in this project line quality dissimilarities are indicators of non-genuineness these dynamics parameters of handwriting are some of the many parameters that examiners use to evaluate a questioned signature in order to reach a conclusion. In order to complete the forgery task the forger is usually performing hesitations and slow non-natural pen movements where are not present in genuine handwriting construction. The line of handwriting when is producing in a smooth way is resulting in a smooth movement in contrast to forger where the pen is moving slowly and this is what appeared and in this research with the parameters velocity and writing duration to be the evidence of this theory validation.

5.2. Study II

Positive steps towards the act of establishment objective methods in order to achieve the scientific validation of forensic handwriting analysis field are the initiatives like the creation of signature complexity models such as the one proposed by Found, Rogers [7] and evaluated here. Study II examined the application of Found, Rogers [7] model to classify signatures that were included in University of Kent’s database and compare this result with the opinion of professional FDEs so as to determine the degree of agreement. The results of Study II although limited and not entirely consistent with the study of Found that proposed this model, indicate that the model can provide valuable objective evidence (regarding complex signatures) in the forensic environment and justify its further investigation but more work is need to be done in order to use this type of models in the court of law.

Of the 150 signatures examined the three FDEs gave the professional opinion about complexity in the range of high medium and low complexity. The three FDEs agreed on 93 of the signatures (61%) whilst in the remaining 57 signatures, at least two of them agree (39%). The statistical model tested in this study classified most signatures as group 3 signatures, meaning high complexity signatures. This result was in contrast with the opinion given by the FDEs. This result was one was a major negative point in the verification of the model based on our own database. Figure 4.9 (page 80) shows the general results for all FDEs' opinion and model predictions that allow us to have a comparative picture of all the tests in their entirety. In addition to this the model was able to predict correctly only 53% of the FDEs opinion regarding the complexity of the signatures. In 25 signatures the statistical model had only one same answer with one out of three of the FDEs (17%), the percentage was slightly lower (13%) in the case that the statistical model agreed with two out of three FDEs in 19 signatures. The highest percentage (24%) found on the third classification where the statistical model agreed with all the three FDE in 36 signatures. This data therefore provides some support for the findings originally documented by Found, Rogers [7] and the model having 53% correct prediction is not clearly but partially in agreement with forensic handwriting examiners regarding those signatures that are included in Kent's database.

5.3. Limitations- Future Work

One of the greatest limitations of this study constitutes the number of participants. Although signatures that were analysed amounted to a great amount of data the results may have been more accurate if more individuals had participated in this project. Analysing a larger amount of signatures could give more evidence about the experimental deviations. More participants would be needed to confirm that conclusions drawn in this thesis apply to the general population of adults with no handwriting difficulties. Although on a relatively small scale of participation, this study with data from professional FDEs nevertheless does provide useful indicators and for future development further to studies already in the public domain.

Another limitation was the fact that the database was designed for a different project, although similar in purpose to identify the difference between forged and genuine signatures. We did not give instructions stressing the desired quality of the simulations and did not define the specifications of the experiment in order to be precisely ascertained which of the experimental instructions were wrong and where different methods could be applied which may contribute to a better result.

As it concerns study II a limitation was the fact that the statistical formula suggested by Found et al [7] for determining complexity signatures although useful is not accurate [68]. This was supported by the fact that three categories are very few to successfully conclude in which of these categories a signature will belong based on its complexity. For example, if two signatures have different measurements but very close to each other, these two signatures are likely to be in a different category based on these results despite of the fact that they are similar. In this line of reasoning, the use of the three-point scale will amplify small differences. We believe that the concept of signature complexity is too differentiated to be captured effectively by a three point measurement scale.

Moreover the statistical formula that was used in this study has been created and designed based on a different signature database that it was used for a different project. We did not have sufficient data for the connection between the primary database and the statistical formula. Therefore this project by attempting to analysis the signature complexity using a formula that is designed modelled on other signatures are likely to affect the final results of this study. The objection of selecting this formula was to determine accurately the margin of error and to design in future a different statistical formula based in university of Kent database.

For future research work more kinematics factors could be considered and added, with the aim to develop a larger pool of parameters in order to provide more information about the difference between forged and genuine signatures. In this project twelve dynamic and three static features of signatures were analysed. It should be taken into consideration that fact that in daily work of forensic document the examiner, more features are evaluated, hence there are many other signatures features that could have been examined and may have improved the results of this study. Apart from that the subjects should be allowed to practice the simulation for a number of days for each signature model. It is possible that more practice and time to become more familiar with the models may lead to a better performance from the simulators attempting to forge the genuine signatures. An additional task for future work could be to compare left handed with right handed and record the differences in the ability of the participants of the two groups to forge a genuine signature. It is more common for people to write with their right hand and left handed people were difficult to find an equal ratio to right handed people in the time scale of this project, thus this could be the object of a future research.

In this experiment three forensic handwriting specialists were asked to classify the signature complexity in three groups (high, medium, low), but this method,as it was mentioned earlier, is not accurate to be captured effectively by a three point measurement scale. Taking as example the study of alwejinse, we can add to the existing research by recording the complexity of a signature as a measurement on a similar continuous scale. The future model of investigating complexity of signatures could also include legibility. There is a little research on legibility and signatures ([2] [68] [74]. Legibility may have a complementary effect on complexity and subsequently might have an effect on the ease of simulating. This is because distinguishable letters, syllables or names may help the simulator in the process of imitating a signature.

Apart from the above investigations in the following chapters there will be a reference at the debate which has started in recent years that is challenging the validity of forensic handwriting experts' skills and at the effort which has begun by interested parties of this sector to validate and standardise the field of forensic handwriting examination and a discussion started. However innovative methods are needed for the development of forensic document analysis discipline. Most modern and effective solution in order to prevent observational and emotional bias would be the development of an automated handwriting or signature analysis system. This system will have many advantages in real cases scenario. In the following chapters there will be an attempt to present the main legal obstacles in relation to the implementation of this notably technological tool in real cases scenario.

6. Challenges to the Admissibility of Forensic Document Expert Testimony

Forensic handwriting or signature examination from the viewpoint of the verification or identification of the writer has a great and long-time tradition of serving legal justice system. Numerous cases have been examined by the court over the years in regards with disputed handwriting with evidence provided by handwriting experts. However in recent years there is an ongoing debate regarding the validity of forensic document examiner's expertise and methodology applied in questioned handwriting cases. According to critics this is based on the fact that there is a lack of quantitative and scientific base behind the methodology of forensic document analysis field [36]. In U.S. Federal Rule of Evidence 702 [84] requires that admissible expert testimony assist the trier of the fact, meaning assist the person who determines facts in a legal proceeding. The Federal Rules 702 and Rule 403 [85] of Evidence report that "Expert evidence can be both powerful and quite misleading because of the difficulty in evaluating it. Because of this risk, the judge in weighing possible prejudice against probative force under Rule 403 of the present rules exercises more control over experts than over lay witnesses." so it is reasonable the criticism made upon forensic science fields to the extent that has as an aim to lead them to further development and progression. The reason for the fact that this field and in general traditional forensic science disciplines have to endure a lot of criticism is the parameters of subjectivity probability estimates that are possible to cause error sources that will affect the final conclusion of each case [86]. A critical potential error source in forensic science can be the use of domain irrelevant information. As Broeders puts it "The method does not meet the scientific standard, there are no safeguards against potentially pernicious effects of observer bias and cognitive contamination due to domain irrelevant information" [87] [88].

6.1. Potential Error Rates of Forensic Document Analysis

6.1.1. Confirmation Bias

The parameter of confirmation bias could lead to an increased number of false conclusions. In this occasions the investigator could have a persistent expectation that the suspect is guilty and the evidence before him is incriminating. It is expected from the forensic scientist to have a certain base rate of inculpation that led him to make the choice to examine specific evidence or suspect and such choices are not taken at random [86]. But in this occasion a forensic scientist will reveal an unexpected high level of confidence without the adequate evidence to support it. Based on his personal feeling will reach his/her conclusion forgetting the fundamental role that has to fulfil towards society. The expert scientists is important to understand the value of expert witnessing to a human life and reach to conclusions accordance the ethics rules of the profession. Forensic scientist have to understand the difference of being an objective forensic scientist of a subjective investigator [88].

6.1.2. Re-Assessment

There are occasions where the prosecutor is not satisfied with the outcome of a case report and can make a re-assessment request. This is something that is reasonable to happen but this re-assessment would be better performed by a different laboratory. However if no other laboratory exists to re-assess the case this revaluation would be made by the same laboratory. This lack of an alternative laboratory solution may cause a potential bias to forensic scientist to change his report. Kerstholt argues that the re-assessment in this case could be insinuating the forensic scientist to come to a different conclusion [88] [89].

6.1.3. Error Rates

In the context of a scientific evaluation an error rare interprets a repeatable, continuous, and consistent operation that is important in order to predict the false negative or false positive result level in a casework [90]. The reasonable result for every casework examined would be the expert examiner using the ground truth of the disputed material to be led to the creation of a correct expert report. There are two types of error in forensic handwriting examination. In type I error means the exoneration of a guilty person the handwriting expert incorrectly concludes that the material in dispute is not written by the known writer. Vice versa type II error means the incrimination of an innocent person and is the case when the examiner wrongfully concludes that the questioned handwriting is written by the same writer. For the assurance of a safe verdict where only guilty people are convicted the two types of errors should be prevented or at least minimized [88].

6.1.4. Subjective Judgment

Last but not least is the matter of the subjectivity of forensic handwriting judgments. The handwriting expert makes an estimation of signature complexity and the overall characteristics similarity of the signature in order to make their conclusions. These evaluations are based on the training and expertise of the expert leaving some room for misestimates and misevaluation. In contrast with DNA evaluation that the frequency and size of population is certain in one of the greater and most important strengths of DNA evidence. DNA uses a statistical approach based on an acceptable population sample without variances and empirical testing [91]. The discrepancies in forensic handwriting analysis can sometime be explained not in the abilities of the experts but in the great level of natural variation that is detected in one individual's handwriting [88].

6.2. Forensic Handwriting Analysis Meets Each Daubert Factor

Having this in mind a debate has started in recent years challenging the validity of forensic handwriting experts' skills and at the same time an effort has begun an effort begun by interested parties of this sector to validate and standardise the field of forensic handwriting examination and a discussion started. The Critics in a law review article titled "Exorcism of Ignorance as a Proxy for Rational Knowledge: The Lessons of Handwriting Identification Expertise" attacked forensic document examination and compared FDE to witchcraft [92]. Forensic document examiners dismissed the article completely because it was filled with inaccuracies, was not a peer-reviewed publication, and the three authors were not trained in forensic document examination. In addition, the aforementioned disadvantages of forensic handwriting discipline have influenced the legal science and in particular the part relating to the admissibility of handwriting experts testimony in court. Next we will refer to legal cases which present the legal development of the forensic handwriting evidence admissibility in the court of law.

Courts have relied on the opinions and testimony of forensic document examiners experts for many decades now. The admission of known writing in order to be compared with questioned writing begun in 1913 with the case Frye v. U.S. [93]. Based in this case the Frye rule was formed which provided that in order to be admitted the testimony of a forensic document examiner the expert should have gained general acceptance in the particular discipline. The Federal Rule of Evidence of the United States in 1975 gave courts more extended powers to decide in regards to the admissibility issue of expert witness [91]. Additional factors are taken into consideration for the admission of scientific evidence after United States Supreme Court ruled in Daubert v. Merrell Dow Pharmaceuticals [94]. With this ruling the attention is not only directed at the professional qualifications of the forensic scientist but also in the methodology that they employ in terms of validity and general acceptance in a particular field of forensic science. The Daubert case set out some guidelines in order to determine the reliability of the admitted scientific evidence [95]. These parameters are as stated in Daubert case:

“1. Whether the theory could be tested,
2. Whether there were standards,
3. Whether there were publications in peer-reviewed literature,
4. Whether there was general acceptance in the particular discipline,
5. Whether a known error rate could be developed.

The novelty introduced by this benchmark case is the fact that it has increased the threshold of admissible evidence in areas that were accepted to the court for many years without any scientific background and has lowered the threshold in those cases where the evidence is formed with the help of novel and high tech systems [91]. This is a great challenge for forensic science fields that lack rigorous supporting data. In 1995 in another benchmark case United States v. Starzecpyzel [96] the Daubert standards, set out to determine the reliability of scientific evidence, were partly overturned to the benefit of forensic document analysis filed. During the hearing of this case was an extensive and analytical description of the benefits of evidence provided by forensic document experts. The court based on these views, expressed at the hearing, ruled that this sector lacks scientific background. Despite the fact of the existence of certification programs, peer reviewed professional journal and other evaluations prerequisites as in other accepted scientific disciplines the court concluded that forensic document examination cannot be regarded as scientific knowledge. Nevertheless this unscientific testimony was not excluded by the court. The threshold of admission was lowered regarding this field. It reasoned that this field did not have to fulfil the Daubert standards, due to the fact that forensic document analysis was not accepted as a scientific field and Daubert applied only to scientific evidence provided from scientific fields. The trilogy of these key cases for the area of forensic document examination completed with the case Kumho Tire v. Carmichael [97]. The court in this case dealt with the question whether Daubert standards can be applied to non-scientific fields. Despite the efforts of a consortium of law enforcement organizations to exclude the field from the Daubert scrutiny, the court sealed the loophole created with the case United States v. Starzecpyzel [96]. It ruled that all expert testimony should pass under the scrutiny of appropriate tests of validity in order to be admissible in court. The following paragraphs explain how forensic handwriting identification meets each Daubert factor in terms of theory proven, education, training, certification, falsifiability, error rate, peer review and publication, general acceptance [91] [95].

6.2.1. Education

To begin with an important requirement for most of the principal forensic organisation is to acquire a university degree. The education parameter is also important in forensic document examination field. Most experts have at least a graduate degree in various fields such as law, mathematics, computer science, chemistry. In recent years many of the forensic document examiner seek to possess a master degree to give them specialised knowledge in their field and the change to contribute to research regarding this field which is imposed after the Daubert case. The popularity of forensic science in general generates the need for the development extra programs for further specialization and education of forensic scientists. The continuous training and engaging in research will also help the development of Quality Management Programs, that all forensic laboratories should have, that include requirements for technical reviews and this it will be another way to reduce the potential rates of errors [95].

6.2.2. Training

An important factor for a forensic scientist is the proper training under the guidance of a qualified forensic document examiner. The approved period of training for a forensic document examiner is a two-year apprenticeship style training program. The apprenticeship program should include study for all the tasks that may be encountered with a FDE. From one point and after, and when will be familiar with all the task fall within the purview of this field, the forensic expert has the chance to specialize between two sub-fields of documents examination. He can choose to specialise in forensic chemistry in regards forensic document analysis or forensic handwriting examiner.

Some scientist choose to exercise both these fields. However trainees have to demonstrate that they have obtain the requirement qualifications and an acceptable level of proficiency during the training period in order to implement what they have learned into practice either in the private or public sector. However the training of a forensic scientist should not terminate by the end of this apprenticeship program. Forensic scientists often enough should participate to continuous learning seminars and conferences and in annually external proficiency tests which are organized by independent laboratories and organisations in order to have an objective judgment of their capabilities and test their professional skills [95].

6.2.3. Certification

Various organizations offer certification for forensic document examiners. However there are some organizations that do not have some specific criteria based on experts' qualification and experience for admission but simply it's enough pay an amount of money premium in order to become accepted as a member. Recognized organizations and with great history in the area have different admission criteria. One of these organisations is the American Board of Forensic Document Examiners (ABFDE). In order to become member of this organisation and obtain certification an applicant must pass under three different tests. These tests include a practical examination, a written examination and at the end an oral examination where the applicant have to defend his examination procedures in a mock trial before a panel of ABFDE Directors. Forensic Specialties Accreditation Board accredited the ABFDE's certification program which became one of the least certification program to achieve this level of recognition and acceptance [95].

6.2.4. Falsifiability

There have been various research projects in all these years of existence of forensic document examination in order to determine the empirical value of this field. In recent years among other topics that are addressed as research topics one of the most debated theories was the individuality of handwriting. This theory was tested and has valuable results for the justification of handwriting comparison. The individuality of handwriting theory have been validated, with the assistance of computer based software. In one of those research a software that was developed by de Sargur Shirari and called CedarFox addressed the matter of “the Discriminability of the Handwriting of Twins” [98]. This research, by comparing handwriting samples of twins and non-twins, found that twins’ handwriting was more similar than those of non-twins. However the handwriting in both of the two groups could be differentiated by computer based software and FDEs and this was a proof of further support to the theory of handwriting individuality. In addition to this research handwriting individuality have been proven within large handwritten databases collected. One of those databases was called FISH and was collected and maintained by the Secret Service of United States since 1991 [95].

6.2.5. Error Rate-Current Research on Expertise

In recent years several studies have been done to prove that forensic document examiners perform better than laymen in terms of the identification and elimination of a writer’s questioned document. Some of these studies were:

1. Kam et al. 1994 proficiency test of forensic document examiners. The outcome of this study found that FDEs had better performance than the non-experts college graduates [99].

2. Kam et al. 1997 conducted a writer identification test that had as an outcome that the professional document examiners were six times more likely to make correct identifications of the questioned handwriting than lay person who participated in this study [100].

3. Kam et al. 2001 in a signature verification test demonstrated that forensic document examiners had an error rate of 0.49% in contrast with the other participants who were lay person and had an error rate of 6.47% [101].

4. Kam et al. performed a writer identification test using non hand printed and hand printed questioned documents. This studied showed that lay person incorrectly identified hand printed documents with an error rate of 40.45% in comparison with FDEs who had an error rate of 9.3% for the same task [102].

5. Sita, Found, and Rogers in their research, Forensic Handwriting Examiners' Expertise for Signature Comparison (Sita et al., 2002), proved that the error rate of FDEs in comparison to those of lay person in the verification of a signature were significant lower [36] [103].

6.2.6. The Existence and Maintenance of Standards Controlling the Operation of the Techniques

After Daubert and especially after Starzecpyzel, there was a great need to set out standards for the establishment of profession methodologies and techniques. The primary source of providing and publishing these standards and guidelines for various tasks in the field is the American Society for Testing and Materials International (ASTM). This organisation has published 21 standards for FDEs to date. SWGDOC (The Scientific Working Group for Forensic Document Examination) which belongs to general framework of FBI forensic science laboratory is also a group which deals with the publication of new standards and reviewing the existing standards regarding Forensic Document Examination [95].

6.2.7. Peer Review and Publication

Various articles written for this field can be found in a variety of peer reviewed journals. In this articles an individual can found the current or traditional methodologies that forensic documents examiners apply to their daily work. Other topic that can be found are experimental methodologies and articles in regards to the admissibility of evidence. Some of these journals are specifically focused in this field, and some examples are Journal of the American Society of Questioned Document Examiners and Journal of Forensic Document Examination. Some other journals have a broader scope in forensic science and some examples of this category are Journal of Forensic Sciences and Journal of Forensic Science International [95].

6.2.8. General Acceptance

In Daubert hearing Justice Blackmun stated that "general acceptance" refers to the acceptance of a technique by the relevant scientific community. The general acceptance of the usefulness and validity of the forensic document examination is shown from the numerous degree programs in forensic science which include in their curriculum courses in Questioned Documents and constitute an equal part of the university curriculum comparing to their fields of forensic science. Another indication of the general acceptance that received FDEs from the forensic society can be seen from the involvement and participation of FDEs in ASTM International recognised forensic organisation, that have discussed above. These recognised organisations accept FDEs as members of the broader forensic science community [95].

6.3. Daubert Trilogy and its Effect to Legal Cases

There are several legal cases and sufficient material for specialists to study in order to understand how the principles of Daubert applied to forensic document examination field. In this section some legal cases will be discussed in order to see if and in what extent Daubert affected the progress of the profession. In 1997 in case U.S. v. Timothy James McVeigh the court decided to accept partly the forensic document examiner by permitting him to demonstrate only differences and similarities and not to express a comprehensive expert opinion [104]. The same decision was taken by the court in In U.S. v. Kent Rutherford in 2000 [105]. These cases had as a result to start more Daubert challenges to cases in regards to forensic document examination [36]. There were cases that forensic document examiners excluded in United States v. Saelee [106] and United States v. Fujii [107] which were the first cases that the court decided to exclude this type of evidence [36]. However these cases were the starting point of the effort started by forensic document community to restore the reputation of the field by re-evaluate the foundations of the profession and inform the legal community for the credibility of this profession. This had as a result the establishment of Daubert Group, which was consisted from FDEs, in order to prepare the document expert for the next Daubert challenge forensic handwriting evidence, which was United States v. Prime [108]. The outcome of this case was successful for forensic document community and led to similar results for FDEs in other Daubert admissibility challenges. The few exceptions of the testimony of experts was the result of lack of preparation by the lawyer of the absence of specialists from the hearings of its own. In recent years was a great effort by the community to successfully meet the Daubert/Kumho standards and with the aid of empirical research to prove and strengthen the foundations of this field of forensic science. Empirical research is an ongoing matter that is a current issue which with many universities and professionals with in order to help and support the further development of forensic document examination [36].

The following cases are used as a small sample of Daubert motions to exclude forensic handwriting analysis testimony and their outcome. There are numerous cases in the first two categories that were impossible to be included due to their large number and may be included in a future research.

Federal Circuit Appellate Courts **Daubert motions to exclude forensic handwriting analysis testimony were denied**
1. U.S. v. Jawara, No. 05-30266 (9th Cir. Sept 2006). **2**. U.S. v. Tunde Adeyi, No. 05-1722-cr (2nd Cir. 2006). **3**. U.S. v. Al James Smith, 2005 U.S. App. LEXIS 23798 (4th Cir. 2005). **4.** U.S. v. Judson Brown, 2005 U.S. App. LEXIS 22703 (2nd Cir. April 2003). **5**. U.S. v. Christopher Mornan, No. 04-1319 (3rd Cir. 2005). **6**. U.S. v. Chris Rutland and Barbara Grams, Crim. No. 02-494(DRD) (3rd Cir. 2004). **7**. U.S. v. Demanjuk, 1:99 CV1193, U.S. District Court, Cleveland, Ohio (6th Cir. 2004). **8**. U.S. v. Prime, 02-30375, D.C. No. CR-01-00310RSL (9th Cir. 2004). **9**. U.S. v. Crisp, 324 F.3d 261, 271 (4th Cir. 2003) (fingerprints and handwriting). **10**. U.S. v. Kehoe, 310 F. 3d 579, 593 (8th Cir. 2002).
U.S. District Courts **Daubert motions to exclude forensic handwriting analysis testimony were denied**
1. U.S. v. David H. Brooks and Sandra Hatfield, EDNY No. 06-CR-550 (S-1) (JS) (2nd Cir. Jan 2010). **2.** United States of America v. Anthony Pendleton, U.S. District Court, Los Angeles, California (9th

Cir. Aug 2009). **3.** U.S. v. Robert Gaulden, D.C. Superior Court 2008 CF2-20509. **4.** U.S. v. Hanner, HW, Pr Pro (3rd Cir. June 2007 **5.** U.S. v. David Lin, Case No. CR 01-20071 RMW (9th Cir. Jan 2007). **6.** U.S. v. William C. Campbell, Civil Action No. 1:04-CV-0424-RWS, 2006 U.S. Dist LEXIS 7442 (11th Cir. Feb 2006). **7**. U.S. v. Ferguson, Case No. 3:03cr019 (6th Cir. Aug 2004). **8.** U.S. v. Shawn Joshua Johnson (5th Cir. April 2004). **9.** U.S. v. Roberto Morejon, Case No. 99-717-CRSeitz (11th Cir. July 2003). **10.** U.S. v. Janet Thornton, Wichita, Kansas (10th Cir. Jan 2003).
Daubert motions that resulted in limiting forensic handwriting analysis testimony
1. Legacy Vision, LLC v. Gary Yeamans, CIV-041320-M, WD OK (10th Cir. June 2005). **2**. U.S. v. Yb-Lem Oskowitz, 294 F. Supp. 2d 379, 384 (E.D.N.Y. 2003). **3**. Wolf v. Ramsey 1:00-CV-1187 (N.D. Ga. March 2003). **4**. U.S. v. Hidalgo, Phoenix, Arizona, U.S. Dist., CR-01-1011-PHX-FJM. **5**. U.S. v. Wanijiku Thiongo, June 2002, Concord, New Hampshire. **6**. U.S. v. Kurtzke, Jan 2002, Chicago, Illinois. **7**. U.S. v. Janeek Wiggan, April 2000, Federal District Court, Southern District of West Virginia Charleston, West Virgina (4th Cir). **8**. U.S. v. Rutherford, 8:99CR120, U.S. Dist Ct (8th Cir. 2000). **9**. U.S. v. Hines, Criminal No. 97-10336 NG, Massachusetts (1st Cir. 1999). **10**. U.S. v. Santillan, WL 1201765 (N.D. Cal) (9th Cir. 1999).
Daubert motions that resulted in the complete exclusion of forensic handwriting analysis testimony
1. U.S. v. Fujii, No. 00CR17, WL 33357453 (7th Cir. Sept 2000). **2**. U.S. v. Saelee, No. A01-0084 CR (HRH) (9th Cir. 2001). **3**. U.S. v. Terry L. Brewer, No. 01 CR 892, N.D. Illinois, 2002 U.S. Dist. LEXIS 6689, April 2002. **4.** U.S. v. Edward Lee Lewis, Criminal Action No. 2:02-00042, in Southern District of West Virginia, Charleston, West Virginia, Aug 2002. **5.** U.S. v. Plaza-Andrades Utica, New York (2nd Cir. 2009).

Table 6.1. Summary of cases after Daubert’s standards

6.4. NAS Report and Implications to Forensic Document Analysis Field

US Congress in 2006 instructed the National Research Council of the National Academy of Sciences (NAS) to review the framework of the provisions of forensic science for United States. NAS assigned a committee, which included various scientists from different fields (legal, science, forensic science) to curry out the study that was commissioned by the Congress. During the years 2007 and 2008 the committee investigated this matter heard numerous presentations for the present status of forensic science from numerous scientists. The outcome of this research was presented in 2009 in the form of a report, stating the findings and the recommendations for the development and upgrading of forensic science. The main noncontroversial recommendations were regarding the increase of funding and the development of further standards for forensic science. In addition to this the committee, proceed with statements about numerous forensic science discipline and pointing to some forensic science discipline without adequate scientific background. NAS report did not find adequate support for “individualization” testimony which is used by forensic handwriting analysis. DNA was the only field of forensic science that has achieved to prove the validity of the methodology consistency, which demonstrate a connection between evidence and a specific individual or source. The rest disciplines of forensic science should apply similar methodology with DNA in order to increase the degree of certainty in their daily work [109].

6.4.1. NAS Report Statements on Handwriting Comparison Analysis

After the comments regarding the general field of forensic science, the NAS report made a brief description of the broader field of forensic document examination. To continue the NAS report emphasised on the sub-field of forensic handwriting comparison and came to the conclusion regarding this sub-field with the following statement “the scientific basis for handwriting comparison needs to be strengthened. Recent studies have increased our understanding of the individuality and consistency of handwriting and computer studies and suggest that there may be a scientific basis for handwriting comparison”. However the committee recognizes that there is usefulness and value of the evidence derived for forensic handwriting comparison. In the legal field however the report was not yet implemented neither influenced the outcome of a legal case. This is because the courts and the legal sector have not had the necessary time to evaluate and then respond to the outcome of the NAS report through the process of a legal case. Another explanation for not responding to NAS report is the fact that after Daupert rulling as mentioned above there were many challenges regarding the admissibility of forensic handwriting analysis. These challenges have as a result to prompt the attacks that questioned the lack of empirical validation discussed in the NAS Report and therefore would be unnecessary to refer to the outcome of this report. The presentations and admission of scientific evidence will be improved when the legal professionals will understand better the forensic science fields. Legal science as forensic science evolve and this fact inevitably at some point will bridge the gap that separates them and lead the two fields to build a mutual understanding of each other characteristics [95] [110].

6.5. Innovative methods of future development of forensic document examination field.

New and innovative methods are needed for the development of forensic document analysis discipline, some of these will be presented in this sub-section of the project.

6.5.1. Blind procedure

One of the most powerful and useful procedure to protect against potential error rate or distorting effects of improper motivations and expectations could be blind testing [111]. Forensic scientists and laboratories could adopt a protocol that will include blind examination with real case samples. This will have as result to minimise error rates and biased conclusions and assumptions based in irrelevant evidence. By eliminating the domain extraneous information the forensic examiner cannot be affected by it. The job of an examiner is becoming more reliable if the examiner does not have the prior irrelevant information that will lead them to a biased conclusion. The blind procedures technique have been applied in virtually all scientific fields in order to minimize the distorting influences of irrelevant information [95].

6.5.2. Automated handwriting or signature analysis system

Apart from the proposed solutions given above the most modern and effective solution in order to prevent observational and emotional bias would be the development of an automated handwriting or signature analysis system. This system will have many advantages in real cases scenario. One of the benefits is the fact that a machine cannot be influenced by extraneous information in order to reach its conclusion. In addition to this the time for the preparation of a case will be reduced drastically. The time which needs a forensic document examiner to make a comparison between two handwritten samples will be much less due to the fact that it takes only a few minutes for the automated system to complete the same task. Furthermore another advantage of this type of systems is the fact that the machine will present the same results when offer the same information, while humans may have some variations in their opinions. However due to the fact that humans professional, can still be more accurate form the automated systems make them more appropriate to express their expert opinions. Other limitations of automated system is that they cannot examine thinks for which it is not programmed to see and therefore cannot include them in their final report. These machines are designed to perform accurately on a specific dataset but this does not imply the performance of the automated system is similar when used on new data. This great limitation makes the system to consider inappropriate to give an expert opinion in the court and can have only a supporting role for forensic document examiners during the examination of a case [88].

6.6. Biometrics

In this chapter we look to a different but complementary way of analysis of handwritten samples in contrast to the analysis made by forensic document examiners. This method is based on an automated analysis of handwritten data. In recent years there is a growing interest to automate the analysis process of an individual's handwriting for security reasons. This has as a starting point the fact that lately a general turn is shown towards the field of biometrics which has become more prominent. That is why the pattern recognition field has a growing interesting in automated the analysis of signature and bridging the gap between forensic document examiners and pattern recognition scientists. Before starting the detailed explanation of signature verification systems specifications, it would be good to make a general introduction to the field of biometrics and give the basic characteristics of this field [34].

The word biometrics comes from the Greek language and contains two Greek words. First is the word “bio” which means “life”, and the second word “metric” which means “to measure”. Biometrics that refer to identification or verification procedures have progressed in the last few decades based on the ease of acquiring the data, acceptance of the public, various unique characteristics of human biology and the high level of security provided.

Biometrics modalities include voice, iris, fingerprint, hand geometry, gait and signature. Other biometrics modalities are in different progress and evaluation stages. Apart for the fact that biometrics modalities are in different maturity stages there is not just one biometric modality that consider to be best for all applications. Many parameters must be taken into consideration when planning to implement a biometric devise. Some of these are security risks, the purpose of the function (verification or identification), data collected, expected user circumstances, overall number of users and other parameters [112].

There five prerequisites of a good biometric system outlined by Clarke which are as follows:

“a) Universality: Every person should have the biometric characteristic.

b) Uniqueness: No two persons should be the same in terms of the biometric characteristic

c) Permanence: The biometric characteristic should be invariant over time.

d) Collectability: The biometric characteristic should be measurable with some practical sensing device.

e) Acceptability: The public should have no strong objection to the measuring or collection of the biometric” [113].

Biometric devices have two modes for implementation either identity or verify. Firstly in the verification mode the system it can confirm and authenticate the individual’s identity based on the identity which they have declared. On the other hand, in the identification mode the system it can determine the individual’s identity among of those who their data are registered in the database. According to the nature of the biometric data and the personal traits taken into account there are have two classes of biometric data, behavioural or physiological. The physiological biometrics are measurements based on biological traits such as face, retina, iris and fingerprint. Instead, in the other class are biometrics of the behavioural traits of individuals, such as handwritten signatures or voice recognition.

Handwritten signatures engage a very important role in the wide area of biometric traits. This is due to the fact that signatures play a vital role in order to verify a person's identity. In modern society, handwritten signatures constitute an established mean of personal verification that is legally accepted in all transactions with financial and administrative institutions. The main drawback of this method is the variations that frequently observed in the signature performance and the fact that they cannot be accurately estimated because writing is a complex motor process that is solely depending on psychophysical state of the author. Automatic signature verification consists of three main phases. These are data acquisition together with pre-processing techniques where the input signatures are enrolled and processed. Then there is the feature extraction phase where the personal features of an individual are extracted and kept in the database of the system. Lastly is the classification phase where the personal features extracted are compares with the features of other signatures that are preinstalled in the database of the system [112].

Signature verification systems can be classified into two categories depending on the method that data is acquired. The two methods are offline and online signature verification. In online signature verification is used specialised hardware (e.g. digitising tablets) to record the pen tip movements on the surface of the tablet. This method of collection of the pen tin movement data has the significant advantage that not only collects the static form of the signature but also the dynamic (speed, pressure, acceleration and many others). This has as a result to provide additional information for the construction of the signature in order to form a safer conclusion. In contrast static systems use an offline acquisition method that collects the signature after the writing process. In this occasion the signature has already been written on a document by one person and the data acquisition is performed afterwards by the device in order to collect the signature and transform it to a digitised image for the analysis through the biometric system for security purposes. The areas in which, these two different data acquisition methods are applied, are also different. Online systems used for the authentication of the user’s identity in order to permit the access in his/her personal. Also these systems can be used to verify credit card purchases. Instead for the verification of handwritten signatures on various document and bank cheques offline systems are being used [112].

6.6.1. Feature Extraction

There are two types of features that can be implemented in signature verification systems functions and parameters. In functions features the signature is characterized in terms of a time function whose values constitute the feature set. Parameters have two sub-categories which are global and local parameters. Global parametes take into acount the wole signature. Global parameters that frequently used are number of pen lifts, global orientation of the signature, number of components, total time duration of a signature etc. On the other hand in local parameters features are extracted from a particular part of the signature. Futher local parameters are divided to component and pixel oriented categories. Fig 1 shows the feture extraction methods mentioned above to make them more easily understood [73].

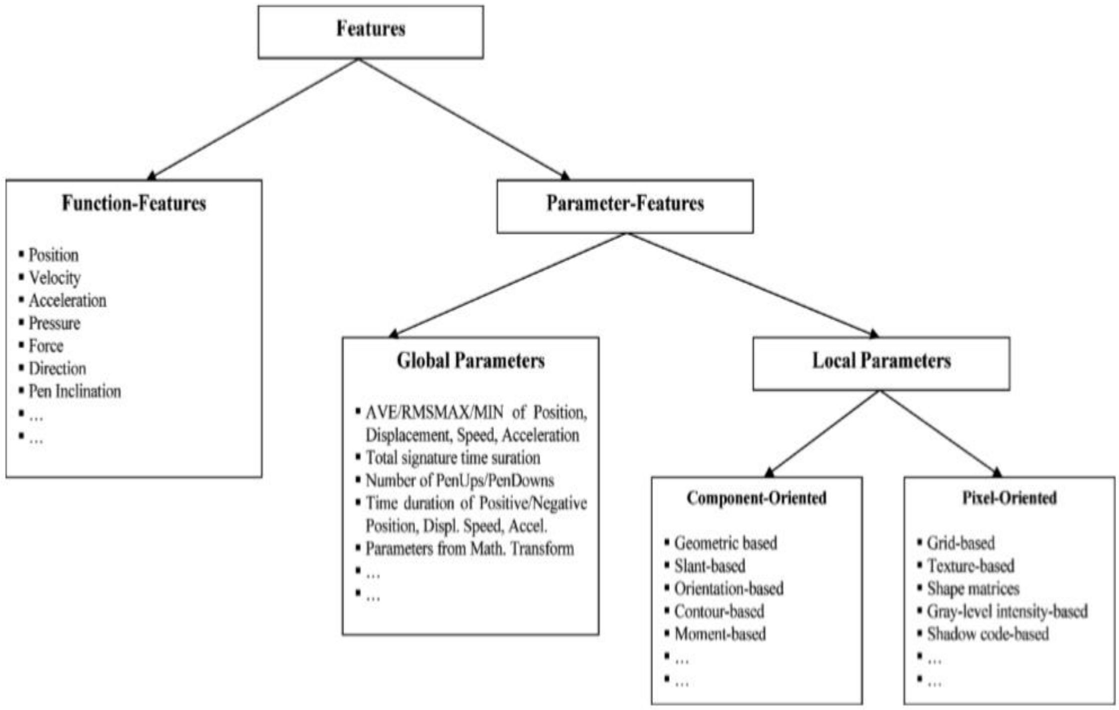


Fig.6.1. Feature extraction categories [73].

6.6.2. Classification

The evaluation of the authenticity of the test signature is taking place in the verification phase. The test signature features are matching against those kept in the knowledge base of the system that developed through the enrolment stage. In this stage the system produces a single response (Boolean value) which determines the authenticity of the exemplar signature. In this case the most common method of comparison is by using algorithms called Dynamic Time Warping (DTW) for signature matching. In the occasions that statistical approaches are used for signature verification a method that can be considered is distance-based classifiers. Another algorithm that has been widely used due to its ability in generalizing and learning is NNs. In recent years there is a special attention in hidden Markov models (HMMS) that can be used for both offline and online signature verification. This algorithm process handwriting data as a sequences of letters rather than as a unit or a single allograph. Artificial Neural Network (ANN) is a different statistical analysis method. AANs are computational or mathematical models good for find patterns and model relationships in data. This method of statistical analysis is based on artificial intelligence and machine learning parameters that are very functional in terms of pattern-based analysis and data mining. Another significant advantage of ANNs is the fact that is functioning well with Bayesian statistics, a method that is used and studied in forensic analysis for probabilities determinations [95]. As Indovo states “The verification process involves many critical aspects that ranges from the technique for signature matching to the strategy used for the development of the knowledge base”. The most common approaches of signatures verification are shown in fig 2. However these approaches are not standard due to the fact that in many cases blended solutions can be chosen [114].

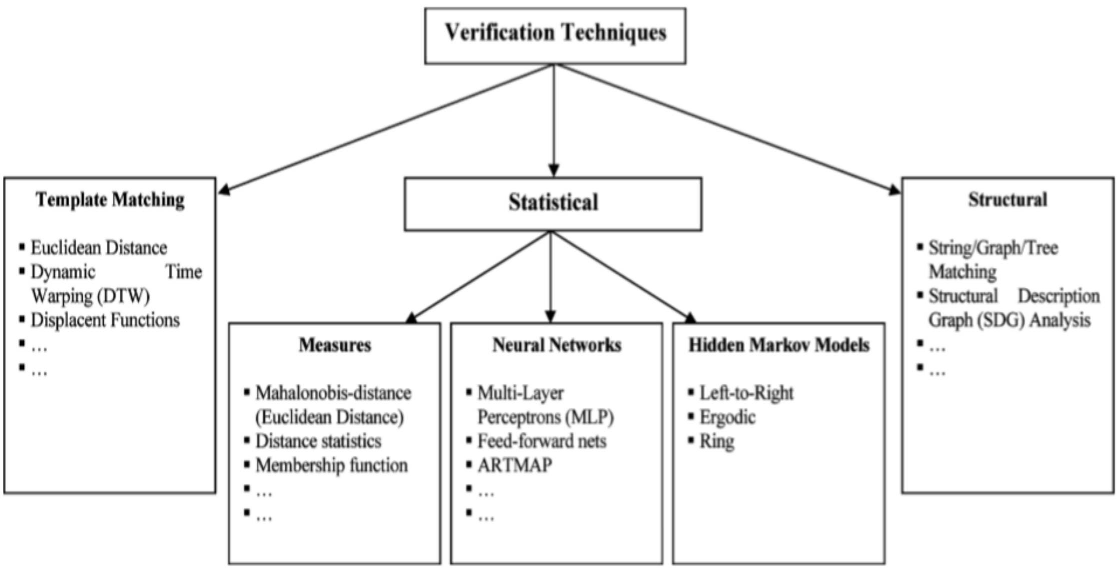


Fig.6.2. Signature verification techniques [73].

6.6.3. Performance Evaluation

Two types of errors are produced in the automatic signature verification. The first error type is called false acceptance rate (FAR) and indicates the case of the false rejection of a genuine signatures. The second type of error concerns the wrong acceptance of a forged signature as a genuine one. This type of error is called false acceptance rate (FAR). Thereby in general terms the performance of a signature verification system is estimated in this manner. The balance between FAR AND FRR must be defined due to the fact that when FRR increases at the same time FAR decreases and vice versa. To add to this in case we FRR is equal to FAR the equal error rate (EER) must be defined and consider to be the overall error measurement of these systems. These types of error can be affected by the fact that the writing is a very complex motor task and it is impossible to determine accurately the variation in the handwritten signature of each author. Another parameter that might increase the overall error of a system is the fact that is not certain the existence of skilled forgers for a given signature and also uncertain is the possibility of collecting forgery samples of adequate quality for the test [73].

6.6.4. Engineering Methods applied in Forensic Science

In recent years and during the debate that is under way concerning the validity of document's examiners methods in analysing handwriting and signature an effort occurred to incorporate automated identification and verification methods into the daily work of document examination field. These methods are based in a great degree in the work that have been done in the field of handwriting recognition technology. The aim of this effort was to objectify and assist the work of document examiners. To continue in this a report will be presented of various projects of computer-based solutions that have been completed in order to be understood the progress degree of automated forensic handwriting analysis systems [114].

6.6.4.1. PEAT (Pattern Evidence Analysis Toolbox)

The first attempt in the field of automated forensic handwriting technology was PEAT. This system that was designed in 1994, had as an aim to provide its user with objective measurements which would be derived from static images of two dimensions. It equips the user with tools capable to measure angles, the path length between any two point, the total area enclosed by the line, the area of any enclosed region and total line length. In addition to this another function of this software is that the users can make direct comparison between the measurements of an original and a disputed documents through the software. At the same year a different system (SCRIPT) was designed that enables experts to make various and detailed measurements in handwriting of an individual that cannot be carried out with the naked eye [114].

6.6.4.2. MATRIX Analysis

Matrix was a software designed in 1998 by the same scientists that invented PEAT system. This system has the same concept with PEAT software which is the fact that enables the users to select measurement points from the handwritten samples in order to proceed to a number of comparisons between them. The system provides the user with an objective score of spatial consistency of the genuine handwriting in comparison to the disputed one. This helps document examiners to determine the variation between the two handwritten samples and reach a conclusion regarding the authenticity of the disputed handwriting [114].

6.6.4.3. FISH WANDA

The next system (FISH) has been used from the central police bureau in Germany (the Bundeskriminalamt) for several years starting 1986. The Forensic Information System for Handwriting (FISH) has as an aim to help automation the work of document examiners and by using the multitask abilities of the system to increase efficiency. Some of the system's computerised abilities is to scan handwritten images and convert them to digitised form. Also the user can carry out measurements of letter characteristics such as distance and hei5ht of letters, store this data and make a comparison between known handwriting and questioned samples. Wanda designed 2003 from an international group of scientist and it was designed to interface with FISH, but in reality the scientist intended to substitute the outdated FISH system. Wanda, in comparison with FISH, has advanced additional handwriting measurements, advanced features and modules that can be regarded as systematic procedure of handwriting examination [114].

6.6.4.4. CEDAR-FOX

CEDAR-FOX forensic handwritten document examination system was presented by S. Srihari and Z. Shi [41]. CEDAR is another automated forensic handwriting analysis system and used in this research, in an attempt to become familiar with this type of technology and also to derive a better understanding of this system capabilities.]. It was designed for automated and semi-automated analysis of scanned handwritten documents, and additionally has strong document storage and retrieval capabilities CEDAR-FOX is a computer-based system for analysing electronically scanned handwriting documents, and searching electronically stored repositories of scanned documents. The system is primarily designed for questioned document examination, and it has a number of functionalities which make it useful for analysing documents or searching handwritten notes and historical manuscripts. Cedar-Fox has many functionalities that can facilitate the work of forensic handwriting experts. The procedure that have to be followed in order to verify questioned signature in Cedar is very simple and easy. A questioned signature is compared to a group of known signatures that the user have to enrol into the system (minimum five signatures), in order the system to be trained at this sample signatures so it can give the result for the signature verification. The system provides an output of a confidence (0-100%) of the signature belonging to the known set of signatures or being a forgery [116].

Automatic signature verification is a very attractive field of research from both scientific and commercial points of view. In recent years, along with the continuous growth of the Internet and the increasing security requirements for the development of the e-society, the field of automatic signature verification is being considered with renewed interest since it uses a customary personal authentication method that is accepted at both legal and social levels.

6.7. Admissibility of Signature Verification Systems as Evidence to the Court

The scientific method is the primary way for testing hypotheses in engineering or scientific disciplines. In this rigid framework the scientist is provided with the necessary answers to resolve uncertainty and this leads to the acquisition and development of adequate knowledge regarding these issues. Modern computational methods based on mathematical models lead to more accurate techniques with increased facility and speed. However there are different rules in the procedure governing the facts that the judicial system has to consider in order to resolve questions and introduce evidence to be considered by the jury or court. For the admissibility of evidence in a court of law there must be a certain evidentiary basis under substantive rules and governing procedural in order the court of law to rule for the admissibility of this evidence and this evidence to be allowed to come into consideration by the jury. Lay testimony has different admissibility rules in comparison with expert witnesses. Government prosecutors in criminal cases should prove that each element that occurs and forms a particular crime has been committed beyond a reasonable doubt by the defendant. In contrast in civil cases the plaintiff has to prove that each element of the civil claim or cause of action has been demonstrated by a preponderance of greater weight of the evidence [116].

This difference in methodology applied at these different disciplines frequent cause frictions regarding the burden of proof that is needed when engineering or scientific evidence is attempted to be introduced in a courtroom. Forensic handwriting analysis is an example of this conflict regarding the evidence presented in the Court by Forensic Document Examiners. Having this in mind and due to the rapid advances in the development of computer-based systems for handwriting analysis the courts in the United States are considering the possibility of the admissibility of evidence derived from these systems in the near future. These systems have been introduced in the context of Daubert or Frye hearings. These hearings set the rules for the admissibility of expert evidence by forensic document examiners regarding handwriting or signature testimony. This study will examine the potential use of computer-based systems for handwriting and signature analysis in a legal proceeding. To achieve this we will focus on the decisions in Kumho Tire and Daubert hearings which provide guidance regarding the admissibility of scientific evidence in the court. In addition other judicial decisions will be discussed in order to examine the issue presented in this chapter [116].

In the day-to-day analysis made by an FDE, there will typically be an absence of direct dynamic information for the writing under analysis. In inferring dynamic information from a static trace it is possible to use computer based solutions to automatically estimate some of the dynamic characteristics of signatures or handwriting samples. The ability to measure such data offers the potential to reduce the time cost in analysing cases, for example by identifying potential areas of interest within samples. Some techniques are already reported in the literature to retrieve such inferred or "pseudo-dynamics". Pressure and other dynamic information can also be determined from images (for example scans) of ink, by utilising image processing techniques, such as grey level segmentation [60]. There are also several methods for recovering the order of strokes in handwritten samples using machine learning based techniques such as Hidden Markov Models operating on a database of words [117] and skeletonisation and processing of the ink trace [118]. These have the advantage of being able to operate purely on scans of samples, requiring nothing more than a scanner and computer. Our study has also shown the time consuming nature of human analysis.

Many machine-based techniques for recovering inferred dynamic data have the potential to be of use in the FDEs day-to-day operations which may be able to either shorten the analysis times or help the examiner to know which areas of interest to concentrate on during a case [114]. This study represents a first step in understanding fundamental processes within the FDE community with a long-term aim of attributing accuracy metrics to subjective techniques of inference. Although on a relatively small scale, this wider study with data from professional FDEs nevertheless does provide useful indicators for future development further to studies already in the public domain. However, beyond this, we have illustrated the potential for extending and enhancing the overall analysis of signatures by using automated techniques, and our results suggest that further development of automated tools to support and supplement human inspection may enable the realisation of powerful inference mechanisms in a forensic analysis context, raising the predictive capabilities of the handwritten signature as a source of valuable forensic evidence.

In the last few years, many computational methods have been implemented to build applications that develop new procedures for criminal law and justice [119]. The applications often use a similarity score between a stored model and a presented biometric and use a corresponding threshold to decide whether authentication will be provided to a person. For example, a biometric signature verification system could be used for fraud detection.

As it has mentioned earlier forensic document examiner draw their conclusions based on their experience and the comparison of the disputed document is done visually without the aid of computer based programs. In forensic casework, the use of a precise threshold is not desirable as evidence often cannot be presented as a binary truth value (i.e. true or false), which is why conclusions are presented in a probabilistic way [120]. However computer based methods that have invented the last decade can be very useful to report objective results and by this way strength the value of evidence in the court of law. As Franke et al stated "Similarity scores could be used to compute the probability that the specific similarities/differences will occur if the prosecution hypothesis is true (the suspect wrote the signature) or if the defence hypothesis is true (another person than the suspect wrote the signature). Thus, results of objective feature selection methods could be used to support the FHEs conclusions and express the strength of evidence numerically instead of verbally. In this competition, we would like to make a first step in bridging the gap between objective biometric methods and forensic expert-based opinion". [121]

One of the most popular computer-based software for the verification of signature is CEDAR-FOX which is an interactive software system to assist the document examiner in comparing handwriting samples. Based on differences between the two feature sets, the system produces a score. The score, known as the log-likelihood ratio (LLR), is the natural logarithm of the ratio of the probability of being written by the same writer and the probability of being written by different writers. [98] The score itself can be discretized by CEDAR -FOX into a nine-point scale analogous to the opinion expressed by the document examiner according an ASTM testing standard. [122]

The combined effect of the Daubert, Starzecpyzel, Joiner, and Kumho decisions has, on some occasions, caused limitations on the testimony of FHEs [94] [96] [97]. Challenges have also come from academia, calling for the discipline to clearly articulate its claims as to the character of the skill and provide empirical research which supports those claims. [91] [97]. Legal applications of probabilistic methods will provide a scientific basis in the document analysis field. Evidence presented in a case at law can be regarded as data, and the issue to be decided by the court as a hypothesis under test. In any case there will be uncertainty about both the ultimate issue and the way in which the evidence relates to it, and such uncertainty can, in principle at least, be described probabilistically. In this project we will try to discover the possibility for the admissibility of this forensic signature verification system as evidence in a legal proceeding.

The criteria set by Daubert case were used in recent legal cases to interpret the potential admissibility of evidence derived from new technological and scientific innovations. A decision of the district court, in United States, was overturned by the Ninth Circuit Court of Appeals accepting the expert testimony that was previously excluded and reported that the expert witness had correctly applied the standardized techniques previously developed by independent laboratories [113]. The court concluded that the challenges regarding the methodology that was used by the expert witness to reach his conclusion must be made at the stage of the main proceedings, before the jury and during the evaluation of the weight of evidence from this body of people sworn to give a verdict in a legal case on the basis of evidence submitted to them in court. The decision regarding the admissibility of the methodology used should not be taken in a judicial predetermination manner but should be examined during “battle of the experts” before the jury as the court stated. It was also reported in this case that “the Pre-trial challenges to expert testimony are overcome when the testimony is shown to be reliable and helpful to the jury”. However the court added that “in order for a scientific technique to be reliable, there must be evidence in the records indicating the methodology can be or has been tested” [213]. In agreement with this statement are the comments made by the Tenth Circuit which mentioned that new and untested methodologies based on novel technological achievements should be excluded as evidence from a legal proceeding [124]. Similarly and on this rationale the District of Columbia Court of Appeals stated that “scientists significant either in number or experience must publicly oppose a new technique or method as unreliable before the technique or method does not pass muster under Frye” [125]. Technology affects and will affect in the future the life of every citizen. Therefore it is reasonable for legal science and legal professional to be positive to these technology innovations which could be auxiliary options in order to prove a claim in court of law. The use of cutting edge tools, if they meet the requirements of Daubert case, combined with the independent confirmation of an expert of the system accuracy should be generally admissible in legal proceedings.

Research done by these systems was used to demonstrate the validity of the forensic documents examiners methodology. The computer-assisted writer verification and identification investigation reported in Srihari’s study [98] was reviewed during the pressure of Daubert hearings in federal cases. An example of such circumstances was the U.S. v. Prime case [126]. In this case there was a motion for exclusion of expert testimony as unreliable. The Ninth Circuit Court of Appeals considered the experiments in the context of this motion done by the criminal defendant. The court in response to this motion in regards to the validity of the forensic document analysis methodology, stated "The Government and [questioned document examiner] provided the court with ample support for the proposition that an individual's handwriting is so rarely identical that expert handwriting analysis can gauge reliably the likelihood that the same individual wrote two samples". The most significant support came from Professor Sargur N. Srihari of the Center of Excellence for Document Analysis and Recognition at the State University of New York at Buffalo, who testified that the result of his published research was that 'handwriting is individualistic' [116]. In Yagman a different case which took place most recently the court had given the permission to a document examiner to testify as to authorship of disputed documents [116] [127]. In this case also the court relied on research reported by Srihari in order to support and constitute the validity of the testimony in connection with the known or potential error rate of the handwriting analysis methodology. In this spirit the court in Gricco stated "the state of the art of handwriting analysis has improved and progressed" [116] [128].

Apart from the advantages that can offer, in the field of forensic handwriting analysis, the implementation of these automated handwriting analysis systems we should consider and the legal obstacles relating to the evidence derived from these systems. In recent years the move towards the deployment of biometric technologies in the public and private sectors make necessary a legal investigation of these new techniques compatibility with the existing legal framework. This project will sets out some issues from the angle of data protection, and standardization of signature verification systems in order to be implemented in practice overcoming legal barriers.

6.7.1. Data Protection and Safeguards for the Protection of Biometric Data

We all know and understand the importance of the signature of each person and the need for adequate security so that it cannot be easily forged by someone else the signature who wants to make a profit using illegal means. By signing, one reveals information about oneself and opens up possibilities to link information about oneself together. This is relevant from a privacy perspective, because “knowledge is power”. With these signature verification systems, the signature becomes target for the criminals and governments and the legal community have the duty to protect the personal data of every individual without turning their back on technological progress. In recent years a lot of people are increasingly concerned about adequate and proper protection of their personal data. Most of European states have data protection regulations that ensuring an extra degree of protection in this sensitive matter of concern.

In Europe, ‘personal data’ is defined as ‘any information relating to an identified or identifiable individual’. Subject to protection is also biometric data that is considered to be a category of personal data. The collection and storage of personal and biometric data in database by the state generally is regarded as contrary to the right of privacy and in order to make this action the state must justify it as necessary [129]. In S and Marper v United Kingdom the European Court of Human Rights (ECtHR) held that:
“The mere retention and storing of personal data by public authorities, however obtained, are to be regarded as having direct impact on the private-life interest of an individual concerned, irrespective of whether subsequent use is made of the data” [130].

A test consisted by three parts is implemented by the courts in the council of Europe and EU in order to decide if it is legitimate for a state to proceed with the collection of private data. That three parameters are a) the act should be in accordance with the law, b) a legitimate aim should be served behind this decision, c) it must be a necessary decision in terms of a democratic society [129].

The existence of safeguards, as it concerns personal data undergoing automatic processing, is a very important safety net for citizens. Adequate safeguards is needed for the collection, storage and processing of biometric data due to the fact that there is always the danger this acts to be considered as a violation of right to privacy [129] [135].

In Marper, the ECtHR stressed that:

“The protection of personal data is of fundamental importance to a person’s enjoyment of his or her right to respect for private… life, as guaranteed by Article 8 of the Convention. The domestic law must afford appropriate safeguards to prevent. The domestic law should notably ensure that such data are relevant and not excessive in relation to the purposes for which they are stored; and preserved in a form which permits identification of the data subjects for no longer than is required for the purpose for which those data are stored. The domestic law must also afford adequate guarantees that retained personal data was efficiently protected from misuse and abuse” [130].

Although in many cases these safeguards are applied in different ways, they share nine common characteristics which will briefly discussed below.

1. Personal data must be collected for specific and legitimate purposes which are stated clearly and in detail

2. Data collected should be of appropriate quality, only the necessary and relevant data should be collected for the accomplishment the initial purposes.

3. In order to proceed with the collection of personal data, there should be the clear consent or knowledge of the individuals whose personal data will be taken.

4. Data subjects there must be appropriately informed for the purpose of collecting their personal data of, they also have to be informed for the authority which is responsible for this data collection, whether disclosure is voluntary or mandatory and if there are any consequences in case of non-provision.

5. In data collection procedure should be applied appropriate restrictions and limitations. This means that the data collected should only be used for purposes that were originally defined and there are restrictions in transferring data public and private organization or other individual and between state organisations.

6. There must be appropriate safeguards and security measures in order to ensure the integrity, security and confidentiality of the personal data collected.

Individuals should have the right to the unlimited and unhindered access of their personal information kept in databases.

8. It should be given the right to people to renew and correct their personal data.

9. An independent data protection authority should exist in order to monitor compliance in regards with data privacy safeguards, investigating complaints and to act on behalf of individuals securing their rights in case the privacy of their personal data has been violated” [129] [135].

6.7.2. Expert Evidence General Requirements and Hearsay in Connection with Electronic Evidence

British Civil code states that the practice direction sets out the general requirements of expert evidence, including duties, in the following terms:

"2.1 Expert evidence should be the independent product of the expert uninfluenced by the pressures of litigation.

2.2 Experts should assist the court by providing objective, unbiased opinions on matters within their expertise, and should not assume the role of an advocate.

2.3 Experts should consider all material facts, including those which might detract from their opinions.

2.4 Experts should make it clear

(a) When a question or issue falls outside their expertise; and

(b) When they are not able to reach a definite opinion, for example because they have insufficient information.

2.5 If, after producing a report, an expert's view changes on any material matter, such change of view should be communicated to all the parties without delay, and when appropriate to the court [136].

Based on these general requirements for expert evidence listed above is reasonable to arise the issue of hearsay regarding electronic evidence. To make it easier to understand the importance of the classification of the testimony a brief reference will take place in regards to hearsay evidence.

Hearsay is referring to the case when a statement made to a witness by a person who is not called to testify as a witness during a legal case, but due to the fact that there are some exemptions to hearsay evidence this definition given may or may not be hearsay. There is hearsay evidence and most probably inadmissible when there is an out of court statement offered by a party and the aim of this statement is the establishment of the truth of the matter asserted. Electronic evidence provided by the signature verification systems can be clearly considered as an out-of court statement but it is not related to the notion “statement” given in hearsay definition in the occasions when evidence taken from a signature verification software presented in court [137].

Taking as example the Federal Evidence rule 801(d) of United States, under this rule the notion statement is defined an action that can be made by a person. Automated machines and therefore signature verification system generate information that cannot be considered as a statement the term that is included in the definition of hearsay evidence [137]. Thus a result given by a signature verification system cannot be a hearsay. Of course it is a fact that human were involved in the setting and the design of these systems and thus these systems carry with them the bias of their designers. This is reasonable to raise some questions regarding the reliability of these kind of systems. Nevertheless, courts have traditionally disregarded the possible hearsay issues associated with such evidence. This is a very important legal point because the evidence coming from these systems could not be accepted and disregarded with a different interpretation of the notion “statement” and so it would make the implementation of these systems in courts impossible [138].

Therefore it is wiser for a lawyer to address any evidentiary concerns by requiring proof that the particular machine or device was working properly and tested for accuracy. This will generate the establishment of Standards for the design and appropriate use of these systems making the results produced of handwriting/signature comparison forensically reliable.

6.7.3. Standardization

Standard regarding a digital signature has been published by NIST (National Institute of Science and Technology). This standard specifies and set the minimum requirements regarding the specifications of the digital signature technology. That standard is describing in an extent text over 100 pages the minimum requirements according quality and security in order to produce digital signatures. Moreover the International Organization for Standardization (ISO) published a standard in connection with biometric data and is named "Biometric data interchange formats" (ISO/IEC 19794:2007). This standard is very important for forensic science as well due to the fact defines the specifications regarding data interchange formats for behavioral, temporal, and handwriting data captured using pen systems or digital tablets. Another important standard in the field of biometrics is BioAPI 2.0 (Biometric Application Programming Interface). BioAPI 2.0 provides the specifications for using within verification systems algorithms, archives and biometric devices. This standardized interface allows multiple software to work using the guidelines of a single protocol. Another significant work of this area is the central Biometric Matching System (BMS) that is being used in Europe [114].

The major drawback is not the existence of standards in electronic, digital and biometrics fields, as the standards exist and follow the technological developments in the industry, but the fact that this industry focuses on cheap and convenient solutions rather that solutions based solely in security. Manufactures of these kind of software must comply with the minimum standards and requirements already established in this field, otherwise these software will be forensically unreliable. A different drawback is the fact forensic examiners and the legal system are not sufficiently aware of the minimum standards and procedures required for capturing and authenticating a signature of these types. A forensic scientist must be familiar with the standards of the system in order to make a successful examination. The same should be the case with a lawyer who must know the general characteristics and minimum requirements according quality and security of a system to be able to examine the user of the system in a cross-examination procedure and thus to pass from judicial scrutiny before applied in practice. Therefore, it is advised that handwriting experts and lawyers should become more aware of electronic signature standards to ensure that the signatures they are examining have been sufficiently and securely captured. These two changes in connection with standards, manufacturers cheap designing solution and the increase of awareness of forensic scientists and lawyers regarding the existence of standards, must be done so these systems can implemented in legal proceedings involving questioned handwriting and signatures [114].

7. Conclusion

Forensic document examiners have shown a greater responsibility and interest for meeting the challenges and recommendations presented in NAS report. In 2009 National Academy Society (NAS) stated that “the legitimization of practices in the forensic science disciplines must be based on established scientific knowledge, principles and practices” [109]. In both private and public sectors many forensic document examiners launched an effort to meet these standards. So for this reason forensic document examiners participated in proficiency testing, received certification in accordance with the guidelines of the relevant organisations, applying their methodology according scientific and training standards, and become members that promote research regarding the validation and credibility of the forensic document analysis field, similar research with the objective of this study [95].

This project constitutes an effort in understanding the fundamental techniques within the forensic document examination community regarding the investigation of questioned signatures. The aim of this study is to validate the current methodology of forensic document examiners by presenting a quantitative approach in the task of examining questioned signatures, using a dynamic analysis of genuine and forged signature in order to find which characteristics of the signatures are easier to be forges and if these findings are in accordance with the features that the experts examiner in this type of cases. Modern technology gives the opportunity to researchers to obtain information by the quantification of the kinematic features of signatures and to verify the findings and conclusions of different research which were based solely on static features. This technique has been used to describe the kinematic characteristics of forgeries behaviours in terms of fifteen preselected features of the database signatures. Our research on the differences in kinematic features between forged and genuine signatures provides strong empirical support for the notion that pressure, velocity, and fluency are important factors in differentiating genuine signatures from genuine signatures. Modern kinematic methods that use digitizing tablets together with specialised software that capture the signature process and return dynamic data, are very powerful tools in collecting and analysing dynamic handwriting and signature data. Databases formed by this process can then be statistically analysed and this data can assist the investigator to reach conclusions regarding the interactions between forged and genuine signatures or any other writing conditions (e.g. disguised signatures). This will have as a result to provide the forensic document examination community with empirical data to support their evaluations of kinematic information from static signatures [6].

The results of this study also underscore the importance of the determination of signature complexity when evaluating a signature during an investigation case. This project attempts to present a quantitative approach regarding complexity of signature by implement a statistical formula by Found et al. [7] in order to evaluate the complexity level of the signatures included in the University of Kent database. These results were compares with experienced FDEs' opinion to determine the success rate of the model and whether it is suitable be implemented in practice. Although on a relatively small scale, this study with data from professional FDEs nevertheless does provide useful indicators for future development further to studies already in the public domain.

Apart from that we have illustrated and presented a potential method of enhancing the signature analysis methodology by using automated techniques such as signature verification systems. We have illustrated the advantages but focus on the disadvantages from legal perspectives and our suggestion is that these systems could offer valuable assistant in the evaluation process of questioned signature but further development needed in order to supplement and support human inspection. This technology may become in few years a powerful inference and evaluation mechanism in a forensic handwriting/signature analysis context, enhancing the predictive abilities of the handwritten signature as a source of valuable forensic evidence [34].

A number of systems have been available and marketable to assist questioned document examiners in performing their daily work in forensic cases, some of them have been mentioned earlier, either by narrowing the number of items to examine or making some forensic tasks effortless, these methods save time and effort for the document examiners. In addition the significant role of computer-assisted handwriting analysis in the daily work of FDE or the judicial system is in agreement with the assessment of the National Research Council that “the scientific basis for handwriting comparison needs to be strengthened”, however it seems that further research is required in order to be able these systems to reach the accomplishment point of this objective [116]. Testing Cedar-Fox functionalities giving us the opportunity to look at the potential and capabilities of these systems we reach to the conclusion that benchmarks of performance may be established, through and test. Moreover the relevant bodies need to conduct further verification contests in order to recognise the exact error rates and establish standards for the implementation of these systems by FDEs.

However there will be always concerns about adapting and accepting new technological innovations. This also occurs with the biometrics field and the practical implementation of the biometric systems in the field of forensic science. Biometrics refers to an automatic recognition of a person based on her behavioural or physiological characteristics. Many forensic laboratories will in future implement biometrics software to assist them, since using biometric is the only way to save time and effort from the many cases that a laboratory has to examine every day. The main advantage of biometric authentication is that behavioural or physiological characteristics of one individual cannot be easily duplicated, stolen or shared. The future of biometrics seems to be bright as more and more public and private organizations desire to operate under higher levels of security. Thereby public organisation, private companies and educational institutions should all play a part in promoting the implementation and improving the functionalities of these systems through continuing research, improved education and development of standards that will prove the reliability of biometrics technology.

We strongly believe that the developments that occurred within the field of forensic document examination in the last 20 years clearly reveal that Daubert decision has played a particularly important role and gave the necessary impetus for changes aiming at the progress of this discipline. If anything, the last twenty years have illustrated that the field of forensic document examination is undergoing significant changes and this is in agreement with the view of Saks who stated that "converging legal and scientific forces are pushing the traditional forensic identification sciences toward fundamental change" and that a "paradigm shift is, and has been underway for several years”. We must continue to pursue knowledge in this discipline and inevitably forensic document examiners have to continuously repeat a never ending process known as discovery.

Events that followed Daubert ruling strengthen the view that we must keep asking questions and aim at new knowledge. Over time as we answer to these questions, it is expected that new questions will uncover leading as in a never ending process known as discovery. Only in this case we will manage to bridge the gap between legal science and natural science enabling technological innovations to be integrated into the methodology of forensic scientists having as sole purpose a safer and more democratic society.

8. References

1. Thomas Chatzisterkotis, “An investigation into how limited space and writing posture affect how a signature is written”, MSc Dissertation project, University of Central Lancashire, 2013-2014.
2. R. A. Huber & A. M. Headrick, “Handwriting Identification: Facts and Fundamentals”, Boca Raton, CRC Press, (1999).
3. Sharifah Mumtazah Syed Ahmad, Loo Yim Ling, Rina Md Anwar, Masyura Ahmad Faudzi and Asma Shakil, “Analysis of the Effects and Relationship of Perceived Handwritten Signature’s Size, Graphical Complexity, and Legibility with Dynamic Parameters for Forged and Genuine Samples”, Journal of Forensic Sciences (Wiley-Blackwell). May2013, Vol. 58 Issue 3, pp 724-731.
4. Slyter, Steven, “A Forensic signature examination” (1995), Springfield, III, U.S.A C.C. Thomas.
5. D. Ellen., “Scientific Examination of Documents: Methods and Techniques”, Taylor and Francis, (2006) 3rd edition.
6. Michael P. Caligiuri, Linton A. Mohammed, “The Neuroscience of Handwriting: Applications for Forensic Document Examination”, 2012 by CRC Press, page 95.
7. Found, B., & Rogers, D. (1996). “The forensic investigation of signature complexity”. In M.L. Simner, c.o, Leedham & AJ. W.M. Thomassen (Eds.), “Handwriting and drawing research: Basic and applied issues”, Amsterdam: IOS Press, pp. 483-492.

8. D.A. Black, “Forged signatures more skilfully written than the true signatures”, Journal of Criminal Law, Criminology and Police Science 53 (1) (1963).

9. Katherine. Koppenhaver, “Forensic document examination principles and practice”, Totowa, New Jersey, Humana Press, 2010, pp. 16-57.

10. A. Herkt, “Signature disguise or signature forgery”, Journal of the Forensic Sciences Society 26 (4) (1986) 257–266.

11. O. Hilton, “Scientific Examination of Questioned Documents”, revised edition, Boca Raton, CRC Press LLC, (1993).

12. Muehlberger, R. J. (1990), “Identifying Simulations: Practical Considerations”, Journal of Forensic Sciences, Vol. 35(2), pp. 368-374.

13. Singh, M. and Singh, S. (1999), “A Group of Simulated Signatures: Their Apparition and Authorship-A Case Study”, International Journal of Forensic Document Examiners, Vol. 5, pp. 441-445.

14. Smith, G. D. (1995), “Simulations and Foreign Handwriting Influence: A Case Review”, International Journal of Forensic Document Examiners, Vol. 1(4), pp. 295-298.

15. Herkt, A. (1986). “Signature Disguise or Signature Forgery?”, Journal of the Forensic Science Society, Vol. 26, pp. 257-266.

16. S.C. Leung, Y.S. Cheng, H.T. Fung, N. Poon, “Forgery 1 — simulation”, Journal of forensic Sciences 38 (2) (1993) 402–412.

17. Gek-Kwee Lee, Bei-Sing Yap, Chiew-Yung Yang, Lee-Tiang Lee, Sock-Kim Tan, and Koon-PuayTan, “A Study on the Levels of Difficulty in the Simulation of Individual Characteristics in a Signature”, Journal of the

American Society of Questioned Document Examiners, Volume 9, Number 1, 2006, pp.29-36.

18. A.S. Osborn, “Questioned Documents”, Second Edition Patterson Smith, New Jersey, 1929.

19. Harrison Wilson R., “Suspect Documents, Their Scientific Examination”, (New York: Frederick A. Praeger, 1958.

20. Vardhan, H.; Sinha, R.; Rai, G.; Raj, B. “Writing Movement Difficult to Simulate: An Experimental Study”, Indian Journal of Forensic Sciences, 1991, Vol. 5, pp. 97-104.

21. Bryan Found, Doug Rogers, Hermann Metz “The objective static analysis of spatial erros in simulation”, Journal of Forensic Document Examination, Vol 12, 1999

22. Richard L. Zweigenhaft, “The empirical study of signature size, social behaviour and personality”, Volume 5, No1, 1977, pp 177-85.

23. Sandra Ramsey, "A Study of the Evolution of Handwriting from Grades Three to Six", The American Society of Questioned Document Examiners, Volume 1, No. 1, 1998, pp 32-39.

24. Raymond Orta M. and Magdalena Ezcurra G, “Neurosciences Applied to Handwriting Examination”, American Society of Questioned Document Examiners, Vol. 10, No. 2, 2007, pp 63-69.

25. Dale O. Jorgenson, “Signature size and dominance”, The Journal of Psychology, volume 97, 1997, pp 269-270.

26. Robert Saudek, "Experiments with handwriting", Published Sacramento, CA: Books for Professionals, 1978.

27. J.Kelly, B. Lindblom, “Scientific Examination of Questioned Documents”, (2006) 2rd edition, Taylor and Francis.

28. R.N. Morris, “Forensic Handwriting Identification”, Academic Press, London (2000).

29. Hilton, O., "Signatures--Review and a New View," Journal of Forensic Sciences, JFSCA, Vol. 37, No. 1, Jan. 1992, pp. 125-129.

30. Thomas Vastrick, “The Uniqueness of Handwriting”, Journal of the American Society of Questioned Document Examiners, Volume 1, Number 1, 1998, pp 4-7

31. M. Vos, S. Strach, P. Westwood, “Document Analysis: Handwriting, Encyclopaedia of Forensic Sciences”, (2000), pp 584-590.

32. O. Hilton, “How Individual are Personal Writing Habits?”, Journal of Forensic Sciences, Vol. 28, 3 July 1983, pp. 683-685.

33. Hilton, O., “Line Quality-Historic and Contemporary Views”, Journal of Forensic Science, vol.32, No1, Jan. 1987, pp.118-121

34. Richard M. Guest, Michael C. Fairhurst, Marjory Abreu and Tristan A. Linnell (2011), “Exploiting Inference Mechanisms in the Assessment of Forensic Document Examination Methodologies for Signatures”, J. Forensic Document Examination, Vol 21, pp. 5-15.

35. Purdy, D.C, Kelly, J.S. and Lindblom, “Scientific Examination of Questioned Document”, Second edition. CRC, Taylor & Francis Group, Boca Raton, FL, 2006, pp. 47-74.

36. Jane A. Lewis, “Forensic Document Examination”, Academic Press 2014, Pages 55–145.

37. Riordan, W.M., Gustafson, J.A., Fitzgerald, M.P., Lewis, J.A., “Forensic Science: Current Issues, Future Directions”, Willey –Blackwell, Chichester, West Sussex, UK, pp. 224-251.

38. Huber, R., “Expert witnesses: in defence of expert witnesses in general and of document examiners in particular”, Criminal Law Quarterly 2(3), 1959, 274-295.

39. ASTM International, ASTM Standard, “Standard guide for examination of handwritten items”, E2290-07a, West Conshohocken, Pennsylvania, 2013.

40. ASTM International, ASTM Standard, “Standard guide for scope of the work of forensic document examiners”, E444-09, West Conshohocken, Pennsylvania, 2013.

41. Bryan Found and Doug Rogers, “Documentation of forensic handwriting comparison and identification method: A modular approach”, Journal of Forensic Document Examination, Vol. 12, 1999, pp. 1-68.

42. Bradford, R. R. and Bradford, R. B., “Introduction to Handwriting Examination and Identification”, Nelson-Hall, Chicago, II. 1992.

43. Totty, R.N., Hardscastle, R.A.and J.Steele, “Can genuine signatures ever be exactly alike?,’’ International Journal of Forensic Document Examiners, vol.2, no. 2, April/June 1996, pp. 146-150

44. H. Nousianen, “Some Observations on the factors causing changes in writing style northern criminal technical journal”, Sweden, Vol. 21 No. 8, 1951, p 92.

45. G. Rouslston, “The Fatigue Factor: An Essay Dealing with the Effects of Physical Fatigue on Handwriting Habits”, (an unpublished report of a study conducted by the RCMP Crime Detection Laboratories) 1959.

46. Asicioglu F, Turan N, “Handwriting Changes Under the Effect of Alcohol”, Forensic Science International, Vol. 132, 2003, pp. 201-210.

47. James G. Phillips, Rowan P. Ogeil, Doug Rogers, “Alcohol Consumption, Dependence and the Spatial Characteristics of Handwriting”, J Forensic Document Examination, Vol. 19, 2008, pp. 15-27

48. Galbraith, N. G., "Alcohol Its Effect on Handwriting”, Journal of Forensic Sciences, JFSCA, Vol. 31, No. 2, April 1986, pp. 580-588.

49. Stinson MD, “A validation study of the influence of alcohol on handwriting”. J Forensic Sci. 1997, 42(3), pp 411--416.

50. Adrian G. Dyer, Bryan Found, and Doug Rogers, “Visual Attention and Expertise for Forensic Signature Analysis”, Journal of Forensic Sciences, Vol. 51, Issue 6, Nov2006, p 1397-1404.

51. Franke K. “Analysis of authentic signatures and forgeries”, Computational forensics. Proceedings of the Third International Workshop on Computational Forensics (IWCF 2009); 2009 Aug 13–14; The Hague, the Netherlands. Berlin, Heidelberg, Germany: Springer Verlag, 2009.

52. Bryan Found, Doug Rogers, Robert Schmittat, “A computer program designed to compare the spatial elements of handwriting”, Forensic Science International 68 (1994) 195-203.

53. U.S. Supreme Court ruling, “Daubert v. Merrel Dow Pharmaceuticals”, 509 U.S. 579, 1993.

54. National Research Council of the National Academies, “Strengthening forensic science in the United States: A path forward”, Washington DC, National Academy Press. 2009.

55. Gerard P. Van Galen, Arend W.A. Van Gemmert "Kinematic and dynamic features of forging another person's handwriting", Journal of Forensic Document Examination Fall, 1996.

56. Sharifah Mumtazah Syed Ahmad, Loo Yim Ling, Rina Md Anwar; Masyura Ahmad Faudzi and Asma Shakil, M.Tech, "Analysis of the Effects and Relationship of Perceived Handwritten Signature's Size, Graphical Complexity, and Legibility with Dynamic Parameters for Forged and Genuine Samples", Journal of Forensic Science, May 2013, Vol. 58.

57. Linton A. Mohammed, Bryan Found, Michael Caligiuri and Doug Rogers, "The Dynamic Character of Disguise Behaviour for Text-based, Mixed, and Stylized Signatures", Journal of Forensic Science, January 2011, Vol. 56.

58. Linton Mohammed, Bryan Found, Michael Caligiuri, and Doug Rogers, "Dynamic Characteristics of Signatures: Effects of Writer Style on Genuine and Simulated Signatures", Journal of Forensic Science, January 2015, Vol. 60.

59. Franke, K., Köppen, M. (2001). "A computer-based system to support forensic studies on handwritten documents", International Journal on Document Analysis and Recognition, Volume 3, Number 4, pp. 218-231.

60. Franke, K., Grube, G., "The Automatic Extraction of Pseudodynamic Information from Static Images of Handwriting Based on Marked Grey-value Segmentation", 11 *JFDE* (17) (1998).

61. Colin Estabrooks, "Measuring Relative Pen Pressure to Authenticate Signatures", Journal of the American Society of Questioned Document Examiners, Volume 3, Number 2.

62. Giuseppe Schirripa Spagnolo, Carla Simonetti, Lorenzo Cozzella, "Superposed Strokes Analysis by Conoscopic Holography as aid for Handwriting Expert", Journal of Optics A: Pure and Applied Optics Volume 6 Number 9.

63. P. Halder-Sinn, K. Funsch. "Intra-individual changes in handwriting features depending on handwriting velocity", Journal of Forensic Document Examination, 11, pp. 1, (1998).

64. J. Phillips, S. Noutsi, C. Hughes, D. Rogers. "Effects of writing speed upon modes of signatures simulation: A kinematic analysis", Journal of Forensic Document Examination, 13-1, (2000).

65. M. Wirotius, A. Seropian, N. Vincent. "Writer identification from gray level distribution", Proceedings of the International Conference on Document Analysis and Recognition, (2003).

66. Found, B. 2012, "Handwriting and Signatures, Comparison of", Wiley Encyclopedia of Forensic Science.

67. Avni L. Pepe, Douglas K. Rogers and Jodi C. Sita (2012). A Consideration of Signature Complexity Using Simulators' Gaze Behaviour. J. Forensic Document Examination, Vol. 22, pp. 5-13.

68. Linda C. Alewijnse M.SC, C. Elisa van den Heuvel Ph.D., Reinoud D. Stoel Ph.D. (2011), "Analysis of Signature Complexity". J. Forensic Document Examination, Vol 21, pp. 37-49.

69. A. M. Wing, "Response timing in handwriting," in Information Process- ing in Motor Control and Learning, G. E. Stelmach, Ed. New York: Academic, 1978, pp. 153-172.

70. H. S. R. Kao, G. P. van Galen, R. Hoosain, “Handwriting pressure: effects of task complexity, control mode and orthographic difference”, Graphonomics: Contemporary Research in Handwriting, 1986, pp. 47-66.

71. Brault, J-J., & Plamondon, R. (1993). “A complexity measure of handwritten curves: Modelling of dynamic signature forgery”. IEEE transactions on Systems, Man, and Cybernetics, 23, 400-413.

72. M.C. Fairhurst, E. Kaplani, and R.M. Guest, "Complexity static signature verification," in in Proc. IWFHR, pp. 565-570, measures in handwritten signature verification," Proc. UAHCI, 2000.

73. Donato Impedovo and Giuseppe Pirlo, “automatic signature verification: the state of the art”, IEEE transactions on systems, man, and cybernetics—Part c: applications and reviews, vol. 38, no. 5, 2008.

74. F. A. Fernandez, M. C. Fairhurst, J. Fierrez and J O. Garcia, “Impact Of Signature Legibility and Signature type in Off-line Signature Verification”, Biometrics Symposium, 2007, pp. 1-6.

75. Found, B., and Rogers, D. (1995). Contemporary issues in forensic handwriting examination: A discussion of key issues in the wake of the Starzepyzel decision. Journal of Forensic Document Examination, Vol 8, pp. 1-32.

76. Sita, J., Found, B., & Rogers, D. (2002). “Forensic handwriting examiners' expertise for signature comparison”, Journal of Forensic Science, 47 (5), 117-1124.

77. Dewhurst, T., Found, B., & Rogers, D. (2007). The relationship between quantitatively modelled signature complexity levels and forensic document

examiners' qualitative opinions on casework. Journal of Forensic Document Examination, 18, 21-40.

78. Found, B., and Rogers, D. (1998). A consideration of the theoretical basis of forensic handwriting examination. International Journal of Forensic Document Examiners, Vol. 4, No. 2, April/June, pp. 109-118.

79. Saks, M.J., & Koehler, J.J. (2005). The coming paradigm shift in forensic identification science. Science, 309, 892-895.

80. Chapran, J., Ujam, C., Fairhurst, M.C., Guest, R.M., "Task Related Population Characteristics in Handwriting Analysis", Proc. Of the IET Conference in Visual Information Engineering VIE 2007, (2007).

81. Frans J. Maarse, Arnold J.W.M. Thomassen, "Produced and perceived writing slant: Difference between up and down strokes", Acta Psychologica, Volume 54, Issues 1–3, October 1983, Pages 131–147.

82. Hans-Leo Teulings, Lambert R.B Schomaker, "Invariant properties between stroke features in handwriting", Acta Psychologica, Volume 82, Issues 1–3, March 1993, Pages 69–88.

83. Tytell, P. (1998) Pen pressure as an identifying characteristic of signatures: Verification from the computer. Journal of the American Society of Questioned Document Examiners, 1(1), 21-31.

84. Rule 702. Testimony by Expert Witnesses Federal Rules of Evidence of United States

85. Rule 403. Testimony by Expert Witnesses Federal Rules of Evidence of United States.

86. Risinger MD, Saks MJ, Thompson WC, Rosenthal R. The Daubert|Kumho implications of observer effects in forensic science: hidden problems of

expectation and suggestion. California Law Review 2002 January; 90 (1): 1-56.

87. Broeders APA, “Of earprints, fingerprints, scent dogs, cot deaths and cognitive contamination – a brief look at the present state of play in the forensic arena”, Forensic Science International 2006; 159: 148-157.

88. Reinier J. Verduijn, “Avoiding Contextual Bias in Forensic Handwriting Analysis”, Institute: Netherlands Forensic Institute, 2010, pp. 4-11.

89. Kerstholt J, Eikelboom A, Dijkman T, Stoel R, Hermsen R, Leuven B. Does suggestive information cause a confirmation bias in bullet comparisons? Forensic Science International 2010; 198: 138-142.

90. Budowle B, Bottrell MC, Bunch SG, Fram R, Harrison D, Meagher S et al. A perspective on errors, bias, and interpretation in the forensic sciences and direction for continuing advancement. Journal of Forensic Sciences 2009 July; 54 (4): 798-809.

91. Saks MJ, Koehler JJ, “The coming paradigm shift in forensic identification science”, Science, 2005, 309, 892-895.

92. Risinger MD, Denbeaux MP, Saks MJ, “Exorcism of ignorance as a Proxy for rational knowledge: The lessons of handwriting identification “expertise””, University of Pennsylvania Law Review 1989, 137, 731-78.

93. Frye v. U.S., 293 F1013 (D.C. Cir. 1923.

94. United States Supreme Court ruled in Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579 (1993).

95. Heidi H. Harralson, “The NAS report: implications for forensic document examiners”, Journal of Forensic Document Examination, Volume 20, 2010, pp. 63-70.

96. United States v. Starzecpyzel [880 F. Supp. 1027 (S.D.N.Y. 1995)].

97. Kumho Tire v. Carmichael [526 U.S. 137 (1999)].

98. Srihari S1, Huang C, Srinivasan H, “On the discriminability of the handwriting of twins”, J Forensic Sci. 2008 Mar; 53 (2), pp. 430-46.

99. Kam, M., Wetstein, J., Conn, R., “Proficiency of professional document examiners in writer identification”, J. Forensic Science, 39 (1), 1994, pp. 5–14.

100. Kam, M., Fielding, G., Conn, R., “Writer identification by professional document examiners”, J. Forensic Science 42 (5), 1997, pp. 778–786.

101. Kam, M., Gummadidala, K., Fielding, G., Conn, R., “Signature authentication by forensic document examiners”, J. Forensic Science, 46 (4), 2001 pp. 884–888.

102. Kam, M., Lin, E., “Writer identification using hand-printed and non-hand printed questioned documents”, J. Forensic Science, 48 (6), 2003, pp. 1391–1395.

103. Sita, J., Found, B., Rogers, D.K., “Forensic handwriting examiner’s expertise for signature comparison”, J. Forensic Science, 47 (5), 2002, pp. 1117–1124.

104. U.S. v. McVeigh, No. 96-CR-68

105. U.S. v. Rutherford, (8th Cir. 2000), 8:99CR120, U.S. Dist. Ct, 8th Cir.

106. U.S. v. Saelee, No. A01-0084 CR (HRH) (9th Cir. 2001).

107. U.S. v. Fujii, No. 00CR17, WL 33357453 (7th Cir. Sept 2000)

108. U.S. v. Michael Prime, 220 F. Supp. 2d 1203 (W.D Wash. 2002) (9th Cir. 2002).

109. Committee on Identifying the Needs of the Forensic Science Community, National Research Council of the National Academies (2009). Strengthening

Forensic Science in the United States: A Path Forward, The National Academies Press, Washington, DC

110. Betty Layne DesPortes, “Handwriting Comparison Opinions Admissibility After the NAS Report, Wiley Encyclopedia of Forensic Science, 2013, pp. 1-5.

111. Saks MJ, Risinger DM, Rosenthal R, Thompson WC, “Context effects in forensic science: A review and application of the science of science to crime laboratory practice in the United States”, Science & Justice, 43 (2), 2003, pp. 77-90.

112. The National Science and Technology Council (NSTC), Subcommittee on Biometrics and Identity Management, “Biometrics Overview”, 2006, pp. 1-10.

113. Clarke, R., “Human identification in information systems: Management challenges and public policy issues”, Information Technology & People, 7(4), 1994, pp. 6–37.

114. Heidi H. Harralson, “Developments in Handwriting and Signature Identification in the Digital Age”, 2012, pp. 65-124.

115. Katrin Franke, Mario Koppen, “A computer-based system to support forensic studies on handwritten documents”, International Journal on Document Analysis and Recognition, 2004, pp. 1-13.

116. Kenneth A. Manning, Sargur N. Srihari, “Computer-Assisted Handwriting Analysis: Interaction with Legal Issues in U.S. Courts”, Computational Forensics, Volume 5718, 2009, pp 137-149.

117. Lallican, P.M. and C. Viard-Gaudin, “A Kalman approach for stroke order recovering from off-line handwriting”, ICDAR, vol.2, 1997, pp. 519-522.

118. Kato, Y. and M. Yasuhara, “Recovery of drawing order from scanned images of multi-stroke handwriting”, ICDAR, 1999, pp. 261-264

119. K. Franke and S. N. Srihari. “Computational forensics: Towards hybrid-intelligent crime investigation”, Information Assurance and Security, International Symposium on, 2007, pp. 383–386.

120. Evett, “Bayesian inference and forensic science: Problems and perspectives. The Statistician”, 1987, pp.99–105.

121. Signature Verification Competition, 10th International Conference on Document Analysis and Recognition ICDAR, Proceedings of the 2009, pp 1403-1407.

122. Sargur N. Srihari, Harish Srinivasan, Kartik Desai “Questioned Document Examination Using CEDAR-FOX”", Journal of Forensic Science, vol. 18 (2007), pp. 1-21.

123. City of Pamona, p. 13, quoting Alaska Rent-A-Car, 9th Cir. 2013.

124. Attorney General of Oklahoma v. Tyson Foods, Inc., 565 F.3d 769 (10th Cir. May 13, 2009) (No. 08-5154).

125. District of Columbia Court of Appeals, Robert e. Pettus, Appellant, v. United States, Appellee, 2012, No. 08-cf-1361.

126. U.S. v. Prime, 431 F. 3d 1147, 1153 (9th Cir. 2005).

127. U.S. v. Yagman 2007 WL 4409618 (C.D.Cal. 2007).

128. U.S. v. Gricco, 2002 WL 746037, *3-*4.

129. Oxford Pro Bono Publico (OPBP), “Biometric Identification and Privacy”, Comparative research prepared for the Centre for Law and Policy Research, India, Law Faculty of the University of Oxford,, 2013, pp. 4-45.

130. S and Marper v UK (2009) 48 EHRR 50.

131. Convention for the Protection of Human Rights and Fundamental Freedoms 1950.

132. Charter on the Fundamental Rights of the European Union, art 52(1).

133. Working Party, ‘Working Paper 80: Working document on biometrics’ (2003) 12168/02/EN [section 3.1].

134. Campbell v Mirror Group Newspapers Ltd [2004] UKHL 22.

135. Els Kindt, “Biometric applications and the data protection legislation - The legal review and the proportionality test”, Datenschutz und Datensicherheit 31(3), (2007), pp. 166-170.

136. Phipson on Evidence 18th Ed., Main Volume, Chapter 33 - Opinion and Expert Evidence, Section 5, Expert Evidence in Civil Proceedings, Sub-section (b) - System Under CPR Summarised, Sub-section (ii) - Expert's Duty to the Court.

137. United States v. Lamons, 532 F.3d 1251, 1263-65 (1 1th Cir. 2008) (comparing machine-generated "statements" with statements of persons and asserting that the best means of advancing the "truth-seeking" process is through the authentication process provided in Rule 90 1(b)(9)).

138. Steven Goode, “The Admissibility of Electronic Evidence”, the review. Of Litigation J, Vol.29 (1), 2009-2010, pp. 42-44.