■ REVIEW ARTICLE

Offline and Online Handwriting Analysis: A Comparative Review

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ABSTRACT

Handwriting analysis dates back to the late 1800s when the persons with knowledge and experience used to analyze the handwriting sample of the author. With the increase of knowledge of the subject and its need in the domain of justice system handwriting analysis, it grew from being an informal subject to an academic subject. Handwriting analysis has been readily used in forensic science investigations. It is one of the major branches of forensic science after fingerprint and DNA wherein maximum cases reports are sought after. The cases received for handwriting analysis are from both the domains of the legal system – civil and criminal. By realizing the importance of handwriting analysis and its further implications in the field, many researchers have tried to include the usage of computer technology for the purpose of analysis. This approach still has no approval in the legal system wherein the accepted method is the offline or manual mode of analysis. This current paper is an approach to first explain in detail both the modes of handwriting analysis – offline (manual) and online (computerized). For online handwriting analysis, different approaches are also reviewed. Along with this, a comparative analysis has been drawn between the two approaches to study the pros and cons of both.

KEYWORDS | forensic science, handwriting analysis, handwriting comparison

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INTRODUCTION

Handwriting is a skill which is a combination of perceptual-motor task, generally denoted as a neuromuscular activity. Accomplished handwriting movements are natural that one is persuaded to oversee their intricacy. Handwriting instigates in the brain where a mental image of figures and letters is formed. Then neural signal duplicates this mental image and sends it to the muscles of the arm and hand via the means nervous system. The resultant output is virtually never a precise match of the original mental image. (Will, 2015)

The chirography of an individual - the manner of writing - is specific and unique to an individual, which is in terms of the size, shape, and manner of execution of letters, style of penmanship, and other ornamentations which are specific to his or her writing chirography, which is uniquely distinctive of his or her writing from others. It has been a well-known fact that the handwriting of any individual begins at the age of two where the child scribbles using a writing instrument and establishes his or her handedness – left, right or ambidextrous. By the time the child learns to imitate different shapes by copying different strokes

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According to Hilton (1982) and Huber (1999), each individual's ability to replicate the letter formations varies from other individuals and this ability is significantly dependent upon the author's perception of the letter or figure image and his or her capacity to replicate the same via the usage of their muscular motion. In other words, each individual has his or her own cognitive capability which significantly affects their handwriting ability. Also handwriting is an art that is perfected through thorough practice and constant repetition. Once an individual has perfected the art of imitation, he/she starts deviating from the copy-book form and start embedding their own individual characteristics into their handwriting, making the art of handwriting a habit and an action of his/her subconscious brain, which repeats the letter formation every time in the same manner. (Mehta, 1970)

Since handwriting is highly individualistic, it has been used for the purpose of identification of individuals. Handwriting is the most common medium of communication among people and has slowly grown into human society as an easy means of identification. With the increased usage of handwriting as a means of authentication, the handwriting of forgery began at a faster rate for committing crimes. Thus, the need for establishing a scientific method for the analysis was needed which was proposed by A.S. Osborn, 1929 and was later modified by O. Hilton 1980, who gave the cardinal rules of handwriting identification and individualization for the purpose of handwriting analysis laying down the foundation of scientific methods for handwriting analysis.

These methods were solely based on the examination of the general and class characteristics of handwriting. It was propounded that the general handwriting features are the style characteristics, which are affected by the penmanship of the writer and individual characteristics are the features which are greatly affected by the chirography of an individual and are highly individualistic in nature which can be used for establishing the individualization of the author in the case of disputed or questioned identity (Sharma, 2018).

Although the popular practice for the analysis of handwriting is the usage of the manual or offline mode of examination based on the identification of similar or dissimilar general and individual handwriting characteristics, there is a copious research work available based on the online mode of handwriting examination, wherein different algorithms are devised to perform the handwriting identification. Along with this the methods of online examination of handwriting includes the methods of online character recognition, text-mining and, author attribution. (Dweik, 1986).

Literature Review

Manual or offline mode of handwriting recognition, examination, and analysis involves the evaluation of both general and individual characteristics which include slant, alignment, skill, speed, movement, proportion of letters spacing, rhythm, the proportion of letters, size of letters, amongst others. Individual characteristics include ornamentation, formation of letters, t-cross bar (position, placement, and length), i-dot

(placement, position, shape), use of pet phrases, punctuation marks, amongst others.

According to Harrison, Burkes and, Seiger in 2009, an author's identification can only be decided when both the components feature – general and individual – are equally used in combination to establish the authorship with no significant fundamental differences and verified natural variations.

In 2018, Sharma propounded that the analysis is carried out to establish the authors' identity by employing adequacy in characteristics analysis, authenticating natural variations and integrating both the general and individual characteristics together.

These observations are in accordance with the cardinal rules of handwriting identification viz., 1. Individualization of handwriting, and 2. Identification of handwriting, both sets of rules consist of 5 rules each. (Hilton, 1980)

Rules of Individualization of handwriting are stated as follows:

1. Each and every matured author has a handwriting, which is personal and individualistic to him or her alone.
2. Deterioration of a writer's writing which can be due to any cause will affect all of the handwriting characteristics and will not be limited to changes in one or two elements of writing.
3. Any author cannot exceed his or her maximum writing capability or skill without putting in tremendous effort and practice over a significant period of time.
4. Any type of attempted disguised or forgery will lead to a substandard quality of handwriting and never superior quality.
5. Rule of natural variation.

Rules of Identification of handwriting are stated as follows:

1. The uniqueness of handwriting is the basis of all identification.
2. Any handwriting is recognized by the amalgamation of all its characteristics and qualities, including both those derived from the writing movement – the general handwriting characteristics and those related to form – the individual handwriting characteristics.

3. Handwriting standard samples – admitted or specimen – are necessary to identify the writer's normal writing ways and also to establish the degree of natural variation of his or her handwriting.
4. To establish that any specimen sample of handwriting was written by an exact person the expert has to prove that all the identifying features are a part of his or her normal handwriting and additionally the variation within the specimen sample is covered in the range of natural variation of writing.
5. The rule for the fundamental difference.

From the foregoing observation , it can be justly assumed that a developed and matured writing is a product of a long period of variation and adaption in accordance with the wants and capabilities of the author which are highly specific to an individual. Due to the complex nature of the development of handwriting habits of an individual, the probability that two different individuals might have similar handwriting which when compared and analyzed with each other will not show the presence of dependable dissimilarities is extremely insignificant. (Ellen, 1997)

Although this is so, it does not mean that comparison and analysis of different samples of handwriting to establish the authorship is easy or forthright. The comparison and analysis of handwritings can never be skillfully achieved by placing the parts of jig-saw puzzle to solve it. The method involves thorough and repeated observations of natural variations and fundamental differences when the samples are compared keeping in mind the factors which affects the handwritings of any individual. (Harrison, 2012)

It has been widely advocated that the handwriting examination is at a cross-roads, due to the subjective nature of the analysis and examination methods and thus poses challenges to its scientific nature. Currently, a copious amount of research has been conducted where computer-based tools are being devised to form a scientific basis for handwriting identification.

These tools come in handy when the analysis is to done for comparison of handwriting and provide visual assistance to the handwriting expert along with providing an automated response

for the degree of match or variation between the suspected and questioned handwriting samples, which, in turn, verify the subjective analysis report or the report generated via manual examination by the expert. Along with this these tools help in creating a database of all the samples examined and analyzed which can be accessed when the authorship of unknown samples is to be determined. There are varied tools available which employ either the usage of image-based input method or real-time data collection method for the purpose of recognition of author (Leedham, 2003). Mentioned below are some of these tools:

1. **FISH** – Forensic Information System Handwriting: this system was made available to the experts in the 1990s, which was developed by the German law enforcement. This system was designed to effectively support the experts to retrieve the closest match of the handwriting under question from the copious database the system was supporting. The drawback of this system was it did not generate any scientific report of the analysis it made.

2. **WANDA Architecture:** FISH was succeeded by another system which was jointly developed by the researchers from Germany, Dutch, and the United States of America. This was an open-source generic architecture-based framework devised for handwriting examination and signature recognition and identification. This system was commonly known as WANDA Workbench. The framework of this system enabled the integration of different systems, like, English, German, Kanji, Arabic, etc.

3. **Cedar-Fox System:** This system was devised by US-based researchers for the purpose of handwriting examination and individualization. This system integrated the tools for handwriting examination and means for automated operations too. When it was made to function in automated mode, it was able to perform author verification, author identification, and signature matching. The identification was done using the available database of standard handwriting samples and a report was generated which was based on quantitative measures of similarity. (Leedham, 2003)

4. Louloudisa, Gatosb, Pratikakisb, and Halatsisa

in 2008, proposed another method, the text line detection method, for handwritten documents. In this technique, they based the detection in three distinct steps viz., 1. Image binarization and enhancement, 2. Usage of block-based Hough transform for detecting the potential text lines and 3. To separate vertically connected characters and assign them to text lines. The performance evaluation of the proposed approach is based on a consistent and concrete evaluation methodology.

5. Verma and Sharma in 2017, proposed a zone identification algorithm and used it to perform online handwriting identification of Gurmukhi characters. Here, they grouped the strokes forming the characters into separate zones and each zone is identified using their allotted support-vector-machine model.

6. Raju, Moni, and Nair in 2014 advocated a novel approach wherein they used a combination of GBF–RLC (which is gradient-based features & run-length count). They used this approach on Malayalam script using a database of 19,800 handwritten characters. Their recognition accuracy was 99.78%. In their approach gradient of image was the intensity of each point and RLC was the count of contiguous group of 1's encountered when the image was scanned from top to bottom and left to right.

7. Lutf, You, and Li, in 2010, came up with another approach for the identification of authors of Arabic handwritings. Their study was conducted using 287 writing samples. They approached the identification problem by first separating the document into letters and diacritics. Then these diacritics were extracted and used to calculate the LBP histogram for each diacritic, which were then concatenated and used handwriting characteristics.

8. Vaidya and Bombade in 2013 presented another method wherein they have used the positional feature extraction method which was primarily based on the positional properties of each pixel present in the image of the character. Via this approach, they reported an accurate assessment of Devanagari and Kannada scripts up to 82.89%, and 85.62%, respectively.

RESULT & DISCUSSION

By nature, humans can never function with constant regularity and precision compared to what machines are for, and due to this, natural variation is part and parcel of each standard handwriting sample which will be provided for the purpose of examination and analysis. This is one of the major reasons that the handwriting sample of one single individual will not be the exact replica of his or her previous writings and will possess some degree of natural variation in them.

With this comes the expert who has to use his or her expertise to perform the assessment whether:
1. the differences observed in the handwriting are a natural variation or are fundamental differences making the authorship different, or
2. when the differences found are falling in the range of natural variation then advocating and provide apt reasons for why the differences observed are in actual the natural variation and the authorship belongs to one individual only. (Saudek 1978: 235)

In addition to the natural variation, there are other factors too that influence the changes in the letter formation of an individual's handwriting. These factors can be summarized as follows:
1. The type of writing instrument, writing material, and writing surface used: ink, pen, writing material, writing surface, etc.
2. The author's ability of realistic maturity.
3. The author's speed of handwriting.
4. The system of handwriting learnt by the author.
5. The author's nationality.
6. The author's degree of visual sensitivity and compliance.
7. The author's power of graphic appearance.
8. The author's chirography, vanity, artifice, and wish to copy others.
9. The author's familiarity with foreign script, special training, education, etc.
10. The author's physical and emotional condition.
11. Any chronic physical impairments the author may have. (Ron Morris, 2000)

Along with these the other factors such as age, ailment or wound; medicine, intoxication, alcohol, drug withdrawal, uncooperative writing position, temperature, weather conditions, fatigue, carelessness, content of the document, using of unaccustomed hand or attempted and/or disguise, need to be assessed while establishing an opinion as these factors greatly influence the natural handwriting of an individual. (Harrison, Burkes and Seiger, 2009)

Collectively, due to these reasons, the opinion of a handwriting expert is subjective in nature and is thus liable for human error. As a measure of judgment is called for, it follows that the comparison of handwriting must be, in a part, a subjective process and consequently liable to human error (NISTIR 8282, 2020).

Purohit, et al in 2016, propounded that handwriting recognition is a growing topic of research in the arena of pattern recognition, and machine learning, as its applications are in varied fields. Both OCR (Optical Character Recognition) and HCR (Handwritten Character Recognition) have been gaining acceptance amongst the researchers. There are vivid techniques and algorithms which have been proposed and advocated for to be used as handwriting recognition systems. But the majority of studies are focused on how to convert the textual form present on a paper into computer-readable form. Table 1 summarizes

System	Accuracy	Purpose
Hand Printed Symbol (HPS) Recognition Method	97%	It extracts the geometric, topologic and local dimensions essential to recognize the letter
OCR for cursive script	88.8%	It implements S&R (segmentation & recognition) algorithms devised for cursive script.
Recognition of handwritten numeral based upon fuzzy model	95% for Hindi and 98.4% for English	The aim is to utilize the fuzzy technique to recognize handwritten figures for Hindi and English figures
HC (Hill Climbing) algorithm meant for handwritten character recognition	93% for uppercase letters	To implement hill climbing algorithm intended to select feature subset
Identification of Arabic alphabets and figures by using optimization feature selection	88% for figures & 70% for alphabets	To implement the method used for feature selection in an optimized manner.

Table 1 Comparison between different online handwritings

S.No.	Method	Advantages	Disadvantages
1	Convolution-al-Neural-Net-work Method	• If Convolutional-Neu-ral-Network is skilled, the accuracy of image recognition is high • This method has been employed to recognize different scripts.	• If Convolutional-Neu-ral-Network is skilled, the accuracy of image recognition is high • This method has been employed to recognize different scripts.
2	Semi-incremental method	• The time taken for analysis is not visible • It studies both the latest & previous strokes	• Should be accompanied by other methods too • IT functioning is more complex than the incremental-method.
3	Incremental method	• The identification process is way simpler than the semi-incremental method	• Problem is encountered when the segmentation step is practised.
4	Line and Word Segmentation Method	• It is an effective method for printed forms of documents	• Cannot detect patterns
5	Part Based Method	• It is an effective method for handwrit-ing recognition	• It can be made more accurate by increasing the sample size training period.
6	Slope-an-Slant-Correction Method	• Due to the simpler segmentation process the accuracy of this method	• It is not best approach for handwriting identifi-cation
7	Ensemble Method	• Highly accurate	• The step of Line seg-mentation of characters effect accuracy rate
8	Zone Method	• Highly accurate	• The image must have higher number of zones to get more accurate results.

Table 2   Pros and Cons of Different Methods

the comparison between different online handwriting recognition systems available on the basis of their accuracy and Table 2 summarizes the advantages and disadvantages of different techniques proposed by different researchers. (Rosyda, Shofia, Purboyo, and Waluyo, 2018).

CONCLUSION

Though there is huge evidence from the copious research which is in favor of the usage of handwriting recognition via online mode, there is a huge resistance from the handwriting experts in using this approach for the purposes of handwriting recognition. The major reasons cited for this resistance are from the cardinal rules of handwriting identification, which specifically mentions that the handwriting of any individual is affected by their age, the type of writing instrument used, the type of writing surface used, along with this the purpose for which the content is being written. It has also been promulgated that the handwriting is greatly influenced by the emotional condition of the author. The experts advocate that these factors will not be considered by an algorithm while performing the examination, making it a tool for performing preliminary analysis or for narrowing down the list of suspects. The usage of the online tools is also found to be limited to the general handwriting characteristics, whereas for forming a confirmatory opinion with regard to the authorship of any handwriting holds its ground on both general and individual characteristics.

The major issue being encountered in the online recognition system is how to recognize and classify the image of the handwritten matter for the purpose of analysis and comparison. Another area wherein the research needs to be done is how to make the computer think like the human brain and make it count the various factors which may affect the handwriting of an individual. This will make the recognition more effective as then the online system will be able to differentiate between natural variation and fundamental differences which is the cardinal rule for comparison of handwriting samples. In the near future, the online mode might serve as a key component of the handwriting comparison process as it will be providing a quantitative report. These systems will also be playing a key role in digitizing the existing paper documents. **IJFMP**

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