

A Review of Robust Automated Handwriting Recognition System

Prachi Bhargav¹

Lovely Professional University, Punjab, INDIA¹

Email - prachibhargav7@gmail.com

Meenakshi Parmar²

Lovely Professional University, Punjab, INDIA

²Email - meenakshiparmar987@gmail.com

Abstract

Handwriting is often used to identify personality characteristics that are expressed by neural patterns in the brain. During the prosecution of any crime, the authenticity of a person's handwriting is often subjected to forensic handwriting analysis in order to ascertain authorship. Automated handwriting analysis is fast, precise, and better than visual inspection at identifying handwriting. It is also effective and free of human errors. One of the most effective forensic science processes is the use of an automated handwriting recognition system. It focuses on determining a person's characteristics or attributes of computer vision and image recognition. To boost precision, the new approach focuses on automated handwriting analysis systems. It is essential to use handwriting recognition software, and it must be developed to understand more languages. This paper reviews some of the most efficient automated handwriting identification systems and emphasizes the importance of such systems in handwriting analysis processes.

Keywords: *Automated Handwriting Recognition System, Image Processing, Acquisition, Pre-Processing, Feature Extraction, Matching*

Introduction

The technical progress at present has led to the discovery of recent ways of human and computer interaction. Automated handwriting analysis is one such innovation. Automated handwriting focuses on determining the characteristics or traits of a person through processing of image and machine vision [1]. It's conjointly performed for the human behavior prediction. Automated handwriting system handles formatting, carries out process of segmentation into characters, and finds out the most probable words. Online handwriting recognition involves various things like it converts the text as the user writes an analog to digital converter or a writing surface and the user inputs are then recognized and are converted in to the letter codes which can be used in computer systems [1].

Also, reckoning on the technology and performance of the system used the speed at that handwriting analysis is finished varies.

Handwriting analysis is an important topic to discuss as handwriting recognition can be utilized in numerous fields. We may employ in the education sector. The study of handwriting plays extensive role in the field of forensic science, helps in analyzing the suspected handwriting found on the ransom notes in the offense like kidnapping [2]. Cursive handwriting analysis is employed by graphology specialists to see the temperament of an individual and in document forgery cases, alteration cases, bank check analysis, handwritten processing on forms, handwriting analysis plays a crucial role in forensic science, it helps to establish the identity of offender from the written documents which are available and forensic examiners get to know about various things through handwriting examination and they can the event thus handwriting analysis is very much relevant to forensic science [3].

Handwriting analysis is challenging because every individual's handwriting differs from each other. Moreover, when a person writes something, the text is not always straight; there may be a slanting up and down, making handwriting more difficult to identify than automated handwriting, which already has a defined type, so it's found to be challenging in nature [4],[5]. Successful recognition of handwriting depends on many factors. The elements of automated handwriting or the online handwriting recognition includes a pen or a stylus which is used by the user to jot down with, a touch sensitive surface is required which maybe integrated with, or adjacent to, an output display, then the foremost necessary a software or a handwriting recognition system is required that interprets the ensuring strokes into the digital text that is needed. While studying about handwriting analysis it is not to be confused with the handwriting systems as biometric systems because the biometric system builds the identity of the person on the basis of certain individual characteristics using the mathematical algorithms and with the use of biometric data we cannot consider handwriting system as the biometric because handwriting of the person keeps on changing under certain conditions and with the passage

of time so handwriting is not a biometric system [6]. Moreover, the question document analysis needs to be automated because when handwriting analysis is performed manually it is subjective in nature. The observations and opinions of two different question document experts may not necessarily match with one another whereas the automated handwriting analysis is objective science. Thus, it is much more needed to avoid contradicting opinions and to get efficient results.

This whole method is classified into four steps: the first step is acquisition, the second is pre-processing, the third step is feature extraction and the last step is matching. First step is obtaining the samples i.e., acquisition. Next pre-processing tools aims to extract by improving the quality of the picture by using specific filters. This stage of system is immersion on cleaning and smoothing of strokes. It includes noise removal, edge detection, bipolarization, normalization and segmentation. In feature extraction we glance for what we tend to truly desires to observe and extract from the samples. These features depend upon either dynamic properties, static properties or both. The features involved in the feature extraction are binary features and non-binary features [1,3]. Then after features gets extracted; we match them and obtain our samples which are required. There are various systems which are used in automated handwriting analysis, they enhance the interaction between the computer systems and human and help us to obtain our analysis efficiently. There are a wide range of methods which can be used for handwriting recognition, which are explained in more detail in the next section.

Various Handwriting Recognition Methods

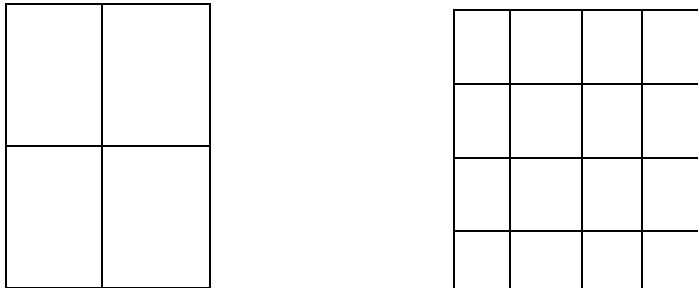
The data collected from the digitizer hardware is processed and then used to produce machine recognized characteristics in online handwriting recognition systems. We have a number of automated handwriting recognition systems, such as: -Zoning method

Handwritten characters are assessed and identified with the use of zoning method. This zoning method is used to describe human perception processes. Analysis of pattern is carried out by using the process of zoning method. While working on the zoning method image containing pattern is further subdivided into zones and each zone gives us some regional information related to a specific part of the pattern. The zoning approach has been commonly used to extract useful data on the local characteristics of patterns, regardless of the feature type used in the handwriting [7].

Static zoning and dynamic zoning methods are the two types of zoning method. In the static zoning method, the zones distribution is evenly or uniformly done and one's and the other's zones are identical. And the more zones we get, the more reliable the image becomes. The standard fraction of the pattern image is included in the static zoning process which is obtained using both the regular as well as non-regular grids and in non-

uniform we had slice- based, shape based and hierarchical zoning patterns [8].

Figure 1. Static Zoning



In the dynamic zoning method, the number of zones the number of zones which are dividing from the large image are not same and the division of zones are not uniform also the magnitude is different. They are designed according to the result obtained from the optimization procedures on which the automated approaches are based upon.

Figure 2. Dynamic Zoning



When we use the automated zoning design, the zoning topology is always designed according to the result of optimization process. And so far, we had come across two types of optimal functions which are the discrimination-based functions and performance-based functions. The discrimination function is considered by the functions of the first category, while the classification accuracy associated with the topology is considered by the functions of the second category.

The estimation of every zone's discrimination ability is an optimization problem which is calculated with the help of the Shannon entropy (E) [7].

$$E = \sum_{i=1}^n P_i \cdot \log_2 \frac{1}{P_i} \quad (1)$$

The number of classes is denoted by the letter n, P_i is the probability.

The features are extracted after changing the location of each zone based on the local pattern information in

this type of zoning system. This is accomplished by bringing each zone closer to the pattern. They are created based on the outcomes of the optimization procedures that the automated approaches are based upon. Thus, the accuracy results of the zoning method are very high and the more the number of zones will be present the more will be the accuracy.

Table 1. The Stages of Image Recognition in the Zoning Method:

Acquisition	The handwriting sample is collected then it is made into an automated database like from each letter several samples will be taken to serve as a database, then we get several zones which are divided on the basis of image which forms patterns depending on the type of zoning method to be used. Then further pre-processing will be carried out [1].
Pre-processing	The pre-processing step is being used to optimize the image quality [1]. It removes the noise present in the picture as well as it makes the feature extraction process simpler. The second stage of pre-processing includes various steps like banalization, resizing the image, median filtering, edge detection, normalization and morphological processes like process of thinning. In this step, the image which is colored is further converted to the grayscale and after that, it is converted to the binary.
Feature extraction	After the pre-processing the feature extraction is carried out and the zoning approach is regarded as one of the most effective in order to extract features [7]. There are two types of zoning methods - the static zoning method and the dynamic zoning method and with the help of both these zoning methods, in order to achieve the desired output, the pattern image's features are then extracted.
Matching	Once the features get extracted the static zoning and dynamic zoning approach are used for the further classification is done to check sample and make the final decision. For testing and training, the input vector from the feature extraction procedure is allocated to the classification model [8]. And it has been noticed that the automated techniques for the zoning designs offer the possibility of designing the best zoning for the requirement of a specific application.

Computer aided graphology method

This method allows graphologists to examine handwriting more easily and reliably using computers. In this method, an input is given, which is a handwriting sample, and then the output is generated, which is the writer's personality profile and other different components of handwriting are analyzed, and forensic investigators use handwriting to assess personality traits [2]. This method is among the approaches that gives quicker and more accurate results. Handwriting review is easily accessible and error free output are achieved and also personality traits of the writer can be described using this method. Manually extracting handwriting features from a given sample of handwriting can be time-consuming and error-prone [7]. We can efficiently achieve error-free results by using the computer aided graphology process.

Table 2. The Stages of Image Recognition in the Computer Aided Graphology Method: -

Acquisition	The handwriting samples are collected and stored as a database Just after that, the handwritten sample is screened and then preprocessing is carried out.
Pre-processing	In the pre-processing the images are cropped to improve the image quality and all the unwanted pixels gets removed and change the RGB image, to Gray scale image then after that output of binary image is produced which is next examined. [7].
Feature extraction	In the feature extraction, the segmentation process takes place and then each segment is studied in order to extract various features present in the handwriting like the direction of lines, slant, strokes, line Spacing, alignment, pen pressure, Letter size and composition, word spacing etc. [9].
Matching	In this step, the output obtained in the previous stage are subjected to interpretation. The free grammar is then applied while matching in a computer aided graphology method to obey the graphology rules. It creates some patterns of strings. Then the alignment is judged, pen pressure is judged, size and proportion of letters are checked and even the position and shape of “i” dots and t-bars. After that only data is made and further investigation is carried out.

The handwriting recognition is efficiently done in this computer aided graphology process, and the writer's personality characteristics can be noted down, such as the upward alignment tells the hopeful, cheerful, or excited traits of the writer. While writing, the writer is pessimistic, emotional, or frustrated, as shown by the

downward alignment. The writer is disciplined and well-organized, as demonstrated by the straight alignment. Then, if we consider pen pressure, we can deduce that if more pen pressure is present then the writer is slow, and illiterates, as well as those who are very emotional, write with a lot of it. Many who write fluently have empathy for others and are sensitive to their feelings and if we see moderate pen pressure, we can interpret that the person is balanced emotionally.

Extroverts and enthusiastic people are often associated with large handwriting, whereas small handwriting is associated with introverts and academic conduct and i-dots can also indicate many things about the writer like if 'i' is written without a dot, it means towards the absent mindedness of the writer and When the dot is put high overhead, it means that the writer is creative and when the dot is then shaped into a ring then that shows that the writer is having artistic personality also open dot signifies a visionary and a close friendship. And just like i-dot, t bars also indicate about the personality traits of the writer like if the letter is written like star that shows that the writer is having strong sense of responsibility. When the crossed bar is tilted up, it demonstrates that the writer is ambitious and if the cross bar is high and also it rises away from stem towards the right side that indicates that the writer is having leadership qualities and the writer is intelligent [10]. Thus, with the help of these features we can interpret the behavioral aspects and personality traits of the writer.

Online signature recognition method

The verification of signature is performed through the online or automated signature recognition method which verifies the signature of the writer and identifies the identity of the writer by using signature verification. This system is also used for the purpose of security such as the verification for entry applications and password substitutions. The above system works on the basis of discrete wavelet transform process and also on neural networks [11].

This approach can be used in both static and dynamic contexts. In static, the user writes their signature on paper, then digitizes it using an optical scanner or camera, after which the biometric device recognizes the signature based on its form and in the dynamic the user writes the signature in a digitizing tablet, which further acquires the signature in real time [12]. And the main objective of this signature verification system is to check if a given signature is genuine or a forgery is done by an imposter. This system identifies individuals based on physiological or behavioral characteristics. Signature authentication necessitates the use of a digitizing tablet and a special pen, both of which are connected to a computer's USB port [13] [14]. The help vector machine approach is also used in this framework to concentrate on signature verification.

Table 3. The Stages of Image Recognition in the Online Signature RecognitionSystem: -

Acquisition	The acquisition is used to acquire the signature of the user with the help of a variety of input tools and stored in a database as the reference templates which are further use in verification stages [13]. In this step, real-time inputs of Signature are read into CPU from the digitizing tablet and special pen. And the digitizing tablet sends real time inputs to the CPU for further processing as well as for storage purpose.
Pre-processing	It contains three steps: - Normalization, resampling time and resampling distance. Because every time a person signs, the signature always differs in size because of paper or any other material. Thus, normalization is needed to make each person's signature same in size before we start to extract its features [13]. And the Normalization of size is always performed by scaling each character both horizontally and vertically. Resampling is done to get all the raw data points equidistant in time using simple linear interpolation algorithms after that all characters have fixed number of points per character.
Feature extraction	It increases the uncertainty, making it easier to distinguish between groups. Pen-up-down, pen orientation, direction, and curvature are among the features derived. Then a binary feature 1 will indicate the pen is touching the pad that means- pen down and 0 will indicate the pen is not touching that means- pen up. After that, a discrete estimation of the first differential with respect to the arc length will be used to calculate the stroke path. The angle between two elementary segments will then be estimated.
Matching	Software validation will give the accuracy of the particular system in verifying signatures. Orientation of the signature is interpreted and if the user signs in wrong orientation, then that mean the signature is forgery signature [15]. Also, pressure while signing would be checked, if shown different pressure while signing a signature that also causes it to be verified as a forgery. Thus, proper match result is obtained without any kinds of error because the forged signatures are hardly verified as genuine signatures.

Method of Line and word segmentation

One of the techniques for handwriting analysis is the line and word segmentation. Segmentation is the most difficult issue in handwriting recognition. And for written papers, this approach yields good results. Several problems occur when recognizing handwritten papers, making the segmentation process more complicated. The first step in any text segmentation process is line extraction. After the lines have been extracted, second step is the segmentation process to change the extracted text lines into individual words [16]. Word segmentation is carried out with the help of two analytical approaches and the holistic approach. In the analytical approach, the words are identified with the help of characters identification the holistic approach of words are created by a single entity and then recognize based on those features [17].

Table 4. Image Recognition in Line and Word Segmentation has following stages: -

Acquisition	The handwriting sample will be collected, then scanned and view scanned images and crop image to find areas of interest [1].
Pre-processing	In the preprocessing existed noise in image is cleared using subtraction method. The resizing of the image will be done and the resize image is deducted from the given image which is blank in nature, for a noise-free image. With the help of mining of the given text and removal of the background the binary image is produced as an output. Thinning is done to remove marked pixels from binary images, [1] much like erosion, for line segmentation, dilation and vertical projection are often used, and a horizontal projection profile is used.
Feature extraction	Hough transform technique is applied to correct false alarms, final set of lines are created, correction of the slant angle of the text line image, the global threshold in the image is determined which is for the gap discrimination and in order to define this global threshold the average of the temporary threshold along all text lines of document image is calculated [1, 18].
Matching	All the text line image, same text line after slant correction, the lines, the zones started from the dotted line to solid line are matched and the overlapped components of the text line image are defined based on the projection profile also

	the Euclidean distance between the adjacent overlapped components are determined with the help of arrows [1,18]. The findings are then assessed in terms of detection rate, with the majority of errors occurring during the word segmentation process, which are generated by non-uniform spacing between words in the same word image, as well as between the image and adjacent words.
--	---

Convolutional neural network system

The Convolutional Neural Network system is a pattern and image recognition algorithm that is commonly used. It is the most commonly used tool for identifying handwriting. Convolutional neural network system is a type of neural network with image recognition that is widely used to analyze visual imagery [1, 19].

Figure 3. Diagram Showing Working of Convolutional Neural Network System

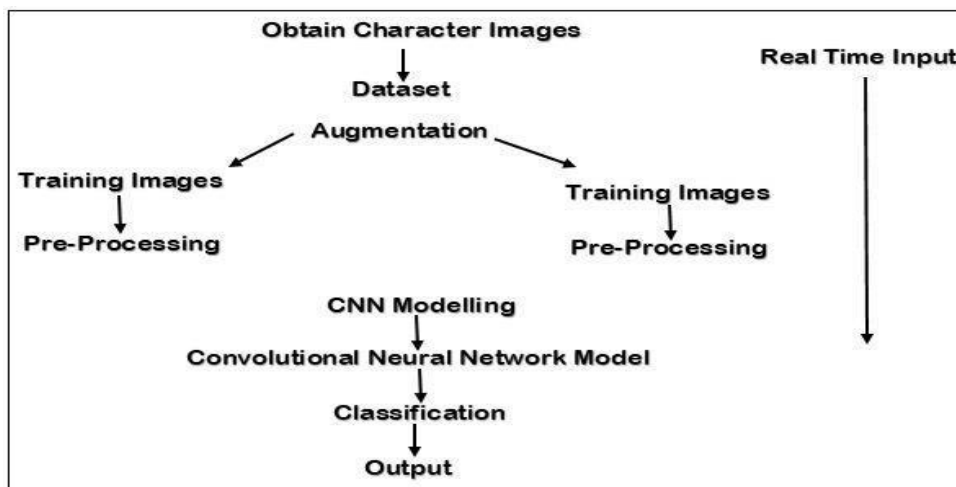


Table 5. The Stages of Image Recognition in Convolutional Neural Network Method: -

Acquisition	<p>A Neural Network is a collection of integrated Artificial Neurons that coordinate with one another. A network consists of various layers of feature detecting the neurons. Each layer covers a wide range of neurons that respond to various combinations of input. CNNs consist of three layers-</p> <ol style="list-style-type: none"> 1. Convolutional Layer- It is the most fundamental layer which make CNN [1]. 2. Pooling Layer- It describes the functions available in a location of the feature map produced by the convolution layer to reduce the complexity. 3. SoftMax Layer- It is the final layer of the CNNs which is further used to recognize the characters [1].
Pre-processing	It is the most usable step in the CNN before entering into the CNN the image

	<p>should go through preprocessing step.</p> <p>The preprocessing steps are as follows: Input the image for identification.</p> <p>Background noise is removed by cropping or wrapping [1].</p> <p>The size of the image is changed if the image is larger than the data will be too large or small which adjusting would be problematic. So, the to attain the uniform size, bigger images are split and padding is attached to smaller images [1].</p>
Feature extraction	<p>In CNN, the Convolutional layer being used for feature extraction. Large data set is required for CNN for this the image that is obtained are adjusted and altered in order to obtain more and large number of variations [1].</p>
Matching	<p>For Classification n and matching the CNN end layer that is SoftMax Layer it is used to Classify the characters and given input image [1].</p>

Recognition of images and patterns, as well as voice recognition, video analysis, and natural language processing are all fields where Convolutional Neural Networks are used. Convolutional Neural Network system's memory use is decreased as a result of enhanced system interfaces requirements [20, 21]. Convolutional Neural Networks have been demonstrated to be efficient in handwriting and machine recognition.

Method of Wireless-inertial-measurement-unit based hand motion analysis

This method aims to recognize handwriting in three-dimensional space. This approach is fully uncontrolled. The users have complete independence and versatility when writing characters in free space. This system uses hand motion analysis and a sensor fusion algorithm that can be used to automatically combine data from multiple sensors differentiate segments that reflect handwriting from non- handwriting data from a WIMU system that records continuous moving objects integrates Magnetic, Angular Rate, and Gravity sensors. Under this system, the dynamic timewrapping technique which is used to get the handwriting in real-time [20] [21]. This device works on the basis of wireless inertial measurement unit-based motion sensor, that has a set of algorithms which are sensor fusion algorithms that allows it to monitor user hand motion in three-dimensional space with precision and accuracy [22]. This system also has challenges because users have different handwriting types and complex changes in timing and pace for each character is difficult to recognize in three dimensions, making three-dimensional handwriting recognition difficult [20,23].

The WIMU system includes MARG sensors as well as a sensor fusion algorithm that identifies hand movements in an intuitive and concise way based on linear accelerations, angular velocities, and hand

orientations ^[21]. Through automatically segmenting hand motion data, this technology includes hand motion method to develop significant handwriting data ^[23].

Figure 4. - Showing Diagram of Handwriting Segmentation and Classification Using WIMU System

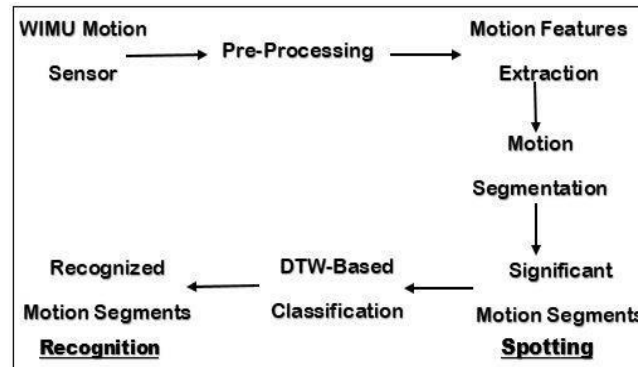


Table 6. Handwriting Recognition's Stages in Wireless –Inertial-Measurement-Unit Based Hand Motion Analysis System: -

Acquisition	It is important to use the WIMU motion sensor. The accelerometer, gyroscope, and also the magnetometer gives accelerations, angular velocities, and magnetic signals generated by hand motion. All of the A microcontroller is attached to the sensors, which collects and processes the information. The data from the wireless motion sensor is then obtained and analyzed at a rate of 100Hz ^[23] .
Pre-processing	Noise, sensor drift, cumulative errors, and the effect of gravitational errors all contribute to inaccurate performance from Inertial sensor Measurements, so the pre-processing phase is critical. In addition, stages involved like the calibration and filtering processes are required to remove noise and errors from inertial signals. To obtain calibrated signals, the calibration process uses the tri-axis accelerometer, gyroscope, and magnetometer scale variables and preferences to minimize the raw signal's sensitivity and offset errors, and low-pass filtering eliminates the high- frequency noise resulting from controlled indicators ^[23] .
Feature extraction	This Wireless inertial measurement unit-based framework detects handwriting and gestures. It is implemented real- time handwriting recognition algorithms based on DTW, which is commonly used to identify human body motion. The WIMU motion sensor's quaternion output is converted into the Euler set of angles of rotation series.

	<p>roll (ϕ), pitch (Θ), and yaw (ψ) are used as features parameters, along with accelerations (a_x, a_y, a_z) and angular velocities (g_x, g_y, g_z), to map and identify handwriting in a meaningful way. The information from motion sensor is taken to create a time series sequence of hand motions, which is denoted by -</p> $m(t) = \{a_x(t), a_y(t), a_z(t), g_x(t), g_y(t), g_z(t), \Theta(t), \psi(t)\}$ <p>Where $t = 1, 2 \dots n$.</p> <p>If the input handwriting content does not meet the threshold value, it is rejected, and through feature extraction, the acceptable minimum total warping is calculated [23].</p>
Matching	<p>After once all the handwriting features gets extracted the locating and identification test for words is performed for matching the images, an examination of digits and English lower case letter letters is conducted, as well as a template file for handwriting and then the qualitative evaluation and discussion is carried out where the examiner asked the suspect set of questions to check the case [23].</p>

GRAPHJ handwriting analysis method: -

GRAPHJ is an automated forensic system that is used to analyses handwriting. This method is the foundation of the entire handwriting recognition system. GRAPHJ employs a variety of algorithms to examine handwritten documents and in order to recognize text lines including words in documents. By producing a report containing statistical data and measurements, this method also simplifies and enhances the documentation of the research process. GRAPHJ is a multimedia tool that automates the measurement of certain quantities related to words and characters [24]. This tool's algorithm performs two tasks: Automated biaxial portion and relative average computations, as well as automated side addition and relative average computations. Furthermore, the implemented algorithms allow the completion of three key tasks: - automated detection of the elements which include the text lines and the words, the quest for instances of a given character is automated and automated Quantities such as the distance between words and characters, as well as the height and width of the character, are measured [24, 25].

Figure 5. Diagram Showing Working Of GRAPHJ- System

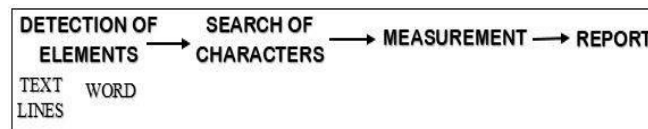


Table 7. The GRAPHJ System's Handwriting Recognition Stages: -

Acquisition	The handwriting samples are collected then The GRAPHJ tool detects text lines and different words within a document automatically, as well as searching for a particular character and detecting its occurrence in handwritten text, it also calculates various quantities associated with the discovered components, such as character height and width, and then produces a report that includes all measurements, data, and parameters used during the study [26].
Pre-processing	To analyses handwritten documents, the proposed tool employs a number of algorithms. The GRAPHJ allows for element detection to be automated, reducing the amount of manual intervention needed. In addition, the examiner may intervene manually to change automatic detections and calculate other quantities including absolute and relative heights [25].
Feature extraction	Many handwriting characteristics, such as regularities and the peculiarities of a handwritten document are obtained through pre-processing in order to define the identity of the writer. The basic stroke forms, in addition to the relative sizes and locations of letters and words [24]. Many forensic experts use a graph metric-based approach to feature extraction, which assesses the various quantifiable features of the handwritten text.
Matching	When considering automated text line search, the text line can be divided into three main sections: a lower section, a median section, and a higher section. The use of automated word detection is being discussed. This method has two steps: first, word boundaries are detected, and then higher and lower section for every word that are present are refined. The GRAPHJ then allows for automatic measurement of certain quantities related to words and characters. This form of analysis, which considers pace and a forgery attempted can be detected through slope and style [26].

Conclusion

This review paper discusses and compares in details, the steps that are involved in the various automated handwriting recognition systems that are available. These Automated handwriting recognition systems must be developed so that they can understand more widely used languages and be used for wider application. Document examiners can retrieve all the acquired data in a very efficient, objective and repeatable way with the use of an automated or computer handwriting recognition systems. Image recognition is a vital process in image processing, and it can be difficult as everyone's handwriting is different. There are many techniques which can be employed in order to determine an individual's handwriting some of which are discussed in this review paper.

Acknowledgement

The authors of this review paper would like to express their acknowledgement to Dr. Mohit Soni, Associate Professor, Lovely Professional University, Punjab, India, for their supervision, assistance, encouragement and guidance for this review paper.

References

1. Kim JH, Sin BK. Online handwriting recognition. *Handb Doc Image Process Recognit*. 2014; 7(4):887-915. doi:10.1007/978-0-85729-859-1_29
2. Mishra A. Forensic Graphology: Assessment of Personality. *Foresic Res Criminol Int J*. 2017; 4(1):12-15. doi:10.15406/frcij.2017.04.00097
3. Srihari S, Leedham G. A Survey of Computer Methods in Forensic Handwritten Document Examination. *Proc Elev Int Graphonomics Soc Conf*. Published online 2003:278-281.
4. Plamondon R, Srihari S. Online_Offline_2000.pdf. Published online 2000.
5. Faundez-Zanuy M, Fierrez J, Ferrer MA, Diaz M, Tolosana R, Plamondon R. Handwriting Biometrics: Applications and Future Trends in e-Security and e- Health. *Cognit Comput*. 2020;12(5):940-953. doi:10.1007/s12559-020-09755-z
6. Bensefia A, Tamimi H. Validity of handwriting in biometric systems. *ACM Int ConfProceeding Ser*. 2018 ;(August):5-10. doi:10.1145/3243250.3243261
7. Rosyda SS, Purboyo TW. A Review of Various Handwriting Recognition Methods. *Int J Appl Eng Res*. 2018;13(2):1155-1164. <http://www.ripublication.com>
8. Impedovo D, Pirlo G. Zoning methods for handwritten character recognition: A survey. *Pattern Recognit*. 2014;47(3):969-981. doi:10.1016/j.patcog.2013.05.021
9. Pasteur L, Koch R. 1. Introduction 1. Introduction. 1941; 74(1934):535-546.
10. Of O, Detecting E, Using P. G LOBAL J OURNAL OF E NGINEERING S CIENCE AND R ESEARCHES. 2019; 273(C):273-280.
- Fahmy MMM. Online handwritten signature verification system based on DWT Features extraction and neural network classification. *Ain Shams Eng J*.2010; 1(1):59-70. doi:10.1016/j.asej.2010.09.007
11. Iranmanesh V, Ahmad SMS, Adnan WAW, Yussof S, Arigbabu OA, Malallah FL. Online handwritten signature verification using neural network classifier based on principal component analysis. *Sci World J*. 2014; 2014. doi:10.1155/2014/381469

12. Julita A, Fauziyah S, Azlina O, Mardiana B, Hazura H, Zahariah AM. Online signature verification system. *Proc 2009 5th Int Colloq Signal Process Its Appl CSPA 2009*. 2009 ;(April 2015):8-12. doi:10.1109/CSPA.2009.5069177
13. Madgude S, Khamgaonkar A, Godhade M. Online Signature Recognition System Based on Artificial Neural Network. 2017 ;(12).
14. Julita A, Fauziyah S, Azlina O, Mardiana B, Hazura H, Zahariah AM. Online signature verification system. *Proc 2009 5th Int Colloq Signal Process Its Appl CSPA 2009*. 2009 ;(April):8-12. doi:10.1109/CSPA.2009.5069177
15. Jindal P, Jindal B. Line and Word Segmentation of handwritten text documents written in Gurmukhi Script using mid point detection technique. *2015 2nd Int ConfRecent Adv Eng Comput Sci RAECS 2015*. Published online 2016:11-19. doi:10.1109/RAECS.2015.7453388
16. Keisham K. Techniques for Text, Line and Word Segmentation. 2015; 3(19):1-4.
17. Halatsis C. Line and Word Segmentation of Handwritten Documents Menu Next Line and Word Segmentation of Handwritten Documents Prev Menu. :2-7.
18. Yang W, Jin L, Xie Z, Feng Z. Improved deep convolutional neural network for online handwritten Chinese character recognition using domain-specific knowledge. *Proc Int Conf Doc Anal Recognition, ICDAR*. 2015;2015-Novem:551-555. doi:10.1109/ICDAR.2015.7333822
19. Altwaijry N, Al-Turaiki I. Arabic handwriting recognition system using convolutional neural network. *Neural Comput Appl*. 2020;33(7):2249-2261. doi:10.1007/s00521-020-05070-8
20. Javed M, Nagabhushan P, Chaudhuri BB. Extraction of line-word-character segments directly from run-length compressed printed text-documents. *2013 4th Natl Conf Comput Vision, Pattern Recognition, Image Process Graph NCVPRIPG 2013*. Published online 2013:3-6. doi:10.1109/NCVPRIPG.2013.6776195
21. Hossen A, Xiufang F, XiaoQiao X, Xin Z. WiHRR: CSI based English Alphabet Handwriting Recognition. *Int J Comput Appl*. 2020; 176(14):31-37. doi:10.5120/ijca2020920068
22. Lee HK, Kim JH. An HMM-Based threshold model approach for gesture recognition. *IEEE Trans Pattern Anal Mach Intell*. 1999; 21(10):961-973. doi:10.1109/34.799904
23. Guarnera L, Farinella GM, Furnari A, et al. Forensic analysis of handwritten documents with GRAPHJ. *J Electron Imaging*. 2018; 27(05):1. doi:10.1117/1.jei.27.5.051230
24. Guarnera L, Farinella GM, Furnari A, et al. GRAPHJ: A Forensics Tool for Handwriting Analysis. *Lect Notes Comput Sci (including Subser Lect Notes Artif Intell Lect Notes Bioinformatics)*. 2017; 10485 LNCS (September):591-601. doi:10.1007/978-3-319-68548-9_54

25. Patil S, Kim D, Park S, Chai Y. Handwriting recognition in free space using WIMU-based hand motion analysis. *J Sensors*. 2016;2016. doi:10.1155/2016/3692876