**Handwriting detection**

## **Abstract**

This is an overview and an improvement for the most recent published approaches to solving the handwriting recognition problem. This paper is aimed at clarifying the role of handwriting recognition in accordance with today’s technologies and algorithms. This paper will try to list and clarify the components that build handwritting recognition and related technologies such as OCR (Optical Character Recognition) and Signature Verification. The motivation of this topic is to recognize the handwriting of a doctor and also for sorting envelopes. Levels of practicality of use of this algorithms and technology for a specific language is also discussed.

# **1. Introduction**

Every individual has different handwriting as unique as the personality traits; even when a similar sentence is written twice by the same person the handwriting may not appear exactly the same [1]. Handwritten characters differ by 12 considerable characteristics: line quality, spacing (line or spaces between character and word), height, width and size of letters, pen lifts and separations, connection strokes, beginning and ending strokes, unusual letter formation, shading (pen pressure), slant, baseline habits, flourishment and embellishments and diacritic placement. External conditions also play a role in affecting the style of handwriting such as the types and colours of ink, pen tip type, smoothness of paper, table surface quality and material, personal emotions, age, gender and speed of the writing process.

Handwriting recognition has been studied for nearly forty years and there are great many proposed approaches. The problem is quite complex, and even now there is no single approach that solves it both efficiently and completely in all settings. In the handwriting recognition process (Fig. 1), an image containing text must be appropriately supplied and preprocessed. Next, the text must either undergo segmentation or feature extraction. Small processed pieces of the text will be the result, and these must undergo recognition by the system. Finally, contextual information should be applied to the recognized symbols to verify the result.

![Diagram

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAGAAAISodpAAQAAAABAAAIUJydAAEAAAAMAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1paGFpAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMxMQAAkpIAAgAAAAMxMQAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure 1. Steps involved in handwriting recognition. Source: [2]

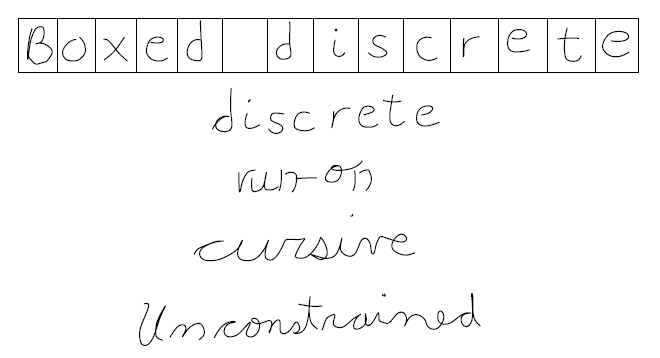
Handwriting recognition can be divided by its input method into two categories: off-line handwriting recognition and on-line handwriting recognition. For off-line recognition, the writing is usually captured optically by a scanner. For on-line recognition, a digitizer samples the handwriting to time-sequenced pixels as it is being written. Hence, the on-line handwriting signal contains.

Research on automated written language recognition dates back several decades. Today, cleanly machine-printed text documents with simple layouts can be recognized reliably by OCR software. There is also some success with handwriting recognition, particularly for isolated handprinted characters and words. For example, in the on-line case, the recently introduced personal digital assistants have practical value. Similarly, some online signature verification systems have been marketed over the last few years and instructional tools to help children learn to write are beginning to emerge. Most of the off-line successes have come in constrained domains, such as postal addresses [10], bank checks, and census forms. The analysis of documents with complex layouts, recognition of degraded printed text, and the recognition of running handwriting continue to remain largely in the research arena. Some of the major research challenges in on-line or off-line processing of handwriting are in word and line separation, segmentation of words into characters, recognition of words when lexicons are large, and the use of language models in aiding preprocessing and recognition. In most applications, the machine performances are far from being acceptable, although potential users often forget that human subjects generally make reading mistakes [9].

Another important technology which is going to be briefly touched here is signature verification [3]. Signature verification if done on-line, could use the same pen-computers as discussed earlier to do a much better analysis of the signature than any human specialist will ever be able to do. Computer driven signature verification systems have much more information available to them, such as the local velocity of the pen-tip at different portions of the signature.

## **2. Methodology (State of the art)**

Hand input is classified into five different types: boxed discrete, discrete, run-on, cursive and unconstrained.



In the case of boxed-discrete input, basically the writer is segmenting his writing into separate characters. This is probably the simplest form of writing to be recognized. In the second type, the writer once again aids the recognizer in segmenting the writing into individual characters. In this case, the problem of segmenting the data into separate characters is solved by finding those gaps between successive chunks of data in the horizontal direction which are greater than a predefined or statistically obtained threshold.

In run-on writing, the problem of segmenting the word into characters becomes nontrivial. In this case, the characters could even overlap such that gap information is no longer sufficient for character segmentation. The only restriction which is imposed on the method of writing run-on is that the pen should be lifted from the surface of the digitizer after each individual character is inputted. One solution to this problem is to treat each stroke of the writing as the smallest unit of the word and conduct a search through reasonable combinations of the stroke labels which could create legal words.

The next type of writing is pure cursive which has even less restrictions imposed on its methodology. For pure cursive, the only two restrictions which are imposed are that there is a pen lift at the end of each word and that all characters are connected to their adjacent character.

Most people however, write in combination of cursive and run-on. This writing style has no limitations imposed other than in some cases there should be a pen-lift after each word. This is the ultimate challenge in handwriting recognition which has attracted lots of attention.

For cursive and unconstrained writings, segments are often defined to be a subset of a character and they are generated based on some criteria set by the recognition algorithm

Markov models of different characters are built at the training stage. The number of states and the probabilities associated with different state transitions and outputs are learned from a training data using techniques such as forward-backward (Baum-Welch) maximization. These models could be build such that they would model the duration of staying at a single state of having null and self transitions. Null transitions are used for skipping states while self transitions provide means of staying at a certain state for a longer duration.

HMMs can be employed in segmentation-based methods to capture the spatial dependencies over nearest neighbors as they were generic models, and try to build joint probability model of label and data. In contrast to this Conditional Random Fields (CRFs) [11] model, the conditional distribution does not create any considerations over the data distribution. CRFs can obtain sum of feature functions unlike HMMs and every feature function can employ the whole sequence of input data.

The authors in [4], proposed a method for off-line handwritten character recognition. The methodology proposed in this paper was based on a feature extraction technique by recursively subdividing the character image. They introduced a two-stage classification scheme. Handwritten character databases such as CEDAR and CIL and handwritten digit databases such as MNIST and CEDAR were used for conducting this experiment. This section describes the problem of handwritten text recognition from a statistical point of view. The handwritten pages are split into lines before recognition and each line is decoded separately. Since the system is supposed to recognize unconstrained texts, no information is available about the content of the data. The only hypothesis made about the lines is that they are written in English. They are thus supposed to respect, on average, the statistics of any fragment of English text. The above aspects will be shown to have an important influence on the recognition results.

When the recognition is performed offline, only the image of the handwritten data is available. The image is converted into a sequence of observation vectors and the recognition task can be thought of as finding a word sequence maximizing the a posteriori probability:

, (1)

where is a sequence of words belonging to a fixed vocabulary V. By applying Bayes theorem, (1) can be rewritten as follows:

(2)

and, since *O* is constant during recognition:

(3)

The right side of (3) shows the role of the different sources of information in the recognition problem. The term *p(O|W)* is the probability of the observation sequence *O* being generated by a model of sentence *W*. This probability is estimated with HMMs.

If *W* is composed of *n* words and the size of the dictionary is [*V*], then the number of possible word sequences is [*V*]n. Even for small values of [*V*] and *n*, this amounts to a huge number, making the task of the recognizer difficult. Moreover, *n* is not known in advance and such an amount must thus be summed over all possible values. The term *p(W)* provides an a priori probability of the word sequence *W* being written and it is often estimated using a *Statistical Language Model*. A good SLM can significantly constrain the search space so that all the sentences that are unlikely to be written (from a linguistic point of view) have a low probability.

In the single word recognition problem, *p(W)* is typically a uniform distribution over the words of the lexicon. This means that the recognition relies only on the HMMs and (3) corresponds to:

(4)

where *w* is a word belonging to the lexicon. In the next section, SLMs and N-gram models, in particular, are described in detail.

## **2.1 Statistical Language Models**

Statistical Language Modeling involves attempts to capture regularities of natural language in order to improve the performance of various natural language applications, e.g., Information Retrieval, Machine Translation, and Document Classification [5]. This section is focused on the use of SLMs in our specific problem, i.e., the decoding of handwritten texts. As shown in (3), the SLM is supposed to give the a priori probability of a certain sentence to be written [6], [7]. If *W* contains n words, *p(W)* can be decomposed as follows:

(5)

where and is referred to as history of word *i*.

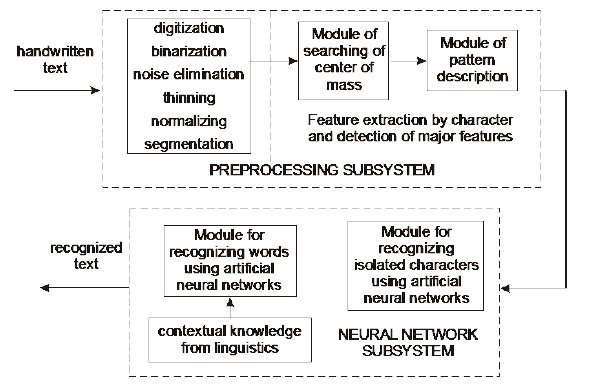
The fact that the probability of word being written depends only on the previous words of the sentence makes decomposition in (5) especially suitable for Viterbi decoding [8]. However, (5) poses an important problem: For a vocabulary of reasonable dimension (in the order of tens of thousands), most of the possible histories appear too few times or even never in a reasonable training set. This does not allow the application of a statistical approach. The solution to such a problem is to group the histories into a tractable number of equivalence classes. Equation (5) can then be rewritten as follows:

(6)

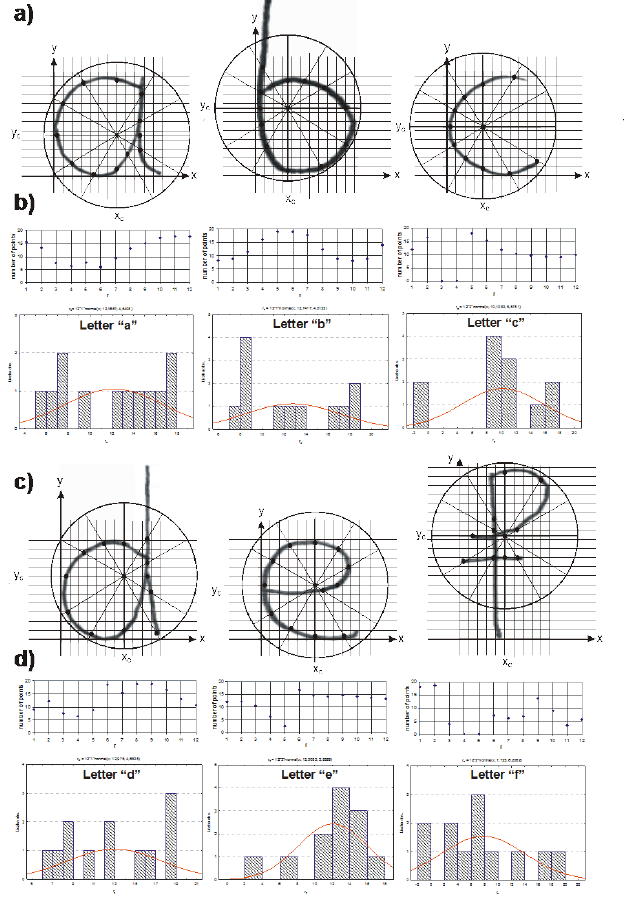
where associates a history *h* to an equivalence class belonging to a finite set *C*.

The nature of allows one to distinguish between the different SLM techniques presented in the literature (see [5] for an extensive survey). In most cases, incorporates some linguistic knowledge.

## **2.2 Neural Network Models**

The handwritten text is made subject to the following preprocessing: digitization, binarization, noise elimination, thinning, normalizing and segmentation. 

The next step is to find the center of mass of the character image. With the center of mass as a reference point, the vectors are drawn, creating a set of points describing the contour of the character so that its pattern description is made. The neural network training patterns are based on the geometric analysis of letters. The description patterns of each isolated character are inputs for an artificial neural network.



## **3. Beyond state of the art**

For performance reasons it is good practice in any of the above systems to incorporate a fast-match algorithm to prune a number of labels which are generated. The idea behind a good fast-match algorithm is to prune the possibilities with little computational effort. It should also insure that the correct label would not be pruned out. Depending on the efficiency of the fast-match algorithm, the recognition time could be considerably reduced.

## **4. Metrics :**

**Character Error Rate**: It is computed as the Levenshtein distance which is the sum of the character substitutions (Sc), insertions (Ic) and deletions (Dc) that are needed to transform one string into the other, divided by the total number of characters in the groundtruth (Nc)

A close up of a clock

Description automatically generated

**Word Error Rate**:  It is computed as the sum of the word substitutions (Sw), insertions (Iw) and deletions (Dw) that are required to transform one string into the other, divided by the total number of words in the groundtruth (Nw)

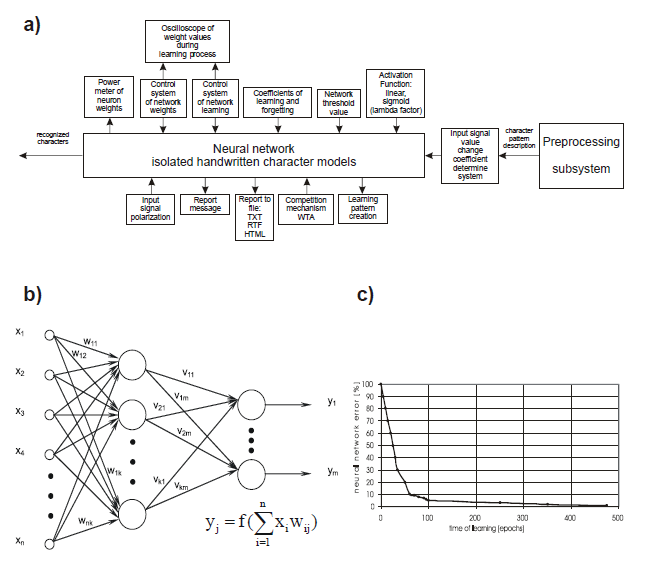
Diagram, schematic

Description automatically generated

[12]In an experiment with 10000 random generated HMM models configured with a combination of random  Q (with value between 3-5) and random M (with value between 3-5) the results starts with a low value of 87.9% and generally increases with an increase specificity threshold. When the specificity threshold is at 0.06, the identification percentage of the SCT drops to 93.8%

[13]The ability of the neural network to learn to recognize specific letters depends on the number of learning epochs. The specified time of learning enables the network to minimize the error so that it could work more efficiently. Based on the research, the following conclusion has been reached as shown in the next fig.

Error rate is about 20% at learning time equals 50 epochs and 5% at 100 epochs. The error rate dropped by about 90% after training with 60 series of all patterns.



# **Bibliography**

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