A Framework of Artificial Immune System in Writer Identification

Azah Kamilah Muda
Kolej Universiti Teknikal Kebangsaan Malaysia,75450 Ayer Keroh, Melaka.
azah@kutkm.edu.my

Siti Mariyam Shamsuddin
Universiti Teknologi Malaysia, 81310 Skudai, Johor.
mariyam@fsksm.utm.my

Abstract

Artificial Immune Systems (AIS) is an emerging computer science technique which is inspired from biological process and has a nonlinear classification property along with biological property such as Negative Selection (NS). AIS has been proved as one of the mechanism that has a good potential in solving complex problem such as pattern recognition. Meanwhile, handwritten writer identification is one of the most popular areas of research in pattern recognition due to its immense potential on commercial perspective. Due to the importance and increasing interest in bio-inspired computing, this paper proposed AIS framework for writer identification. However, early findings on data iris and pendigits show that the proposed framework is convincing with an accuracy of more than 80.0% with various matching techniques.

1. Introduction

In the development of digital age, the paper documents are still exchanged. It involved research concepts from several disciplines: experimental psychology, neuroscience, physics, anthropology, education, forensic document examination, etc [1], [2]. In some situation, writer identification is needed in identifying the original writer of a handwritten document without a signature, where some document do not have any signature such as in threaten letter. The individual handwriting and the author identification for questioned handwritten document have a great importance on the criminal justice system [3].

Handwriting has long been considered individualistic and writer individuality rests on the hypothesis that each individual has consistent handwriting [4]. It brings the handwriting as one of the biometric identification that based on the behavioral characteristics as handwriting analysis in pattern recognition area. It ignited the researchers to explore this field in order to find the best technique to identify the writer of handwriting. It still poses a challenge because human capability is beyond to computerized system in observing and recognizing the style of handwriting. Handwriting analysis can be divided into on-line, where information is captured by transducer device and off-line, where the scanned image of handwriting is used. Offline handwriting based writer identification still being a challenge issues [5] because compared to online writer identification, it is harder to achieve a good identification result because useful information on time order and dynamics of the writing process can not be captured in off line system [6].

Artificial Immune System (AIS) computational technique has led to the development of useful computational tools for the solution of complex problems such as in pattern recognition, fault detection, classifications, computer security, and optimization [7], [8], [9], [10]. The original work by [11] which negative selection algorithm has been inspirational to almost all the research in the AIS related to computer security [12]. In pattern recognition, most of the researches are also influenced by Negative Selection Algorithm (NSA) besides Clonal Selection Algorithm (CSA).

In the work of pattern recognition, Immune System (IS) is performed by using 3 mechanisms which are Negative Selection (T-cells that recognize self-antigens are excluded from the population of T-cells during the maturation process), Clonal Selection (if B-cell encounters a non-self antigen with a sufficient affinity, it will proliferates and differentiates into memory cells) and Immune Network (if B-cell recognizes a self-antigen, it might result in suppression). This study is to explore and apply the capabilities of AIS in pattern recognition, specifically in off-line handwritten writer identification domain.

This paper is organized into several sections. Writer identification is described in Section 2, followed by related AIS works in pattern recognition in Section 3. Section 4 gives a proposed framework of AIS in writer identification, and finally, a conclusion in Section 5.

2. Writer Identification

One of the areas in pattern recognition is handwriting analysis. It consists of two categories, which are handwritten recognition and handwritten identification.

Handwritten recognition is a task of recognize the exact word or character written by individual and interpret the message convey. On the other hand, handwritten identification will distinguish writers based on the shape or individuality style of writing, while ignoring the meaning of the word or character written. It will identify the original authorship of handwriting. In order to identify the author of questioned document, there are two tasks that usually being done which are identification and verification. Identification task is to determine the author of a sample document from many writers. Meanwhile, verification is to determine whether between one question document and one suspect document are written by the same person.

Handwriting is a skill that is personal to individual [2] and individualistic [4]. The relation of character, shape and the styles of writing are different from one to another. Features of handwriting are different according to these varieties of handwriting styles. The main issue in writer identification is how to get the features that reflect the varieties of handwriting [13],[14], where it is the feature extraction task. Extracting and selecting the meaningful features is a crucial step in the process of pattern recognition because it will be used in the classification step. Classification task is to partition the feature space into regions and its symbolic class corresponding to source data samples that the classifier has learned during its training stage.

Most of the researchers in pattern recognition tried to solve the writer identification problem based on the image processing and pattern recognition technique [5]. [5] and [14] list the steps as four tasks : pre-processing, feature extraction, specimen matching and performance identification evaluation. However, [15] mentioned it involve three traditional steps in writer identification which are :

1. Pre-processing : the image is cleaned by noise reduction, then lines and words are extracted.
2. Feature extraction : features which are quantitative measurements are used to discriminate the writers as well as possible; they can be global or local and structural or statistical.
3. Classification : the search of the nearest writer is guided by the extracted features using an adapted metric.

These two kinds of scheme are based on the typical pattern recognition framework. Both of them consist of feature extraction and classification task. In pattern recognition community, it is a well known that feature extraction and classification task are important to achieved a good performance in recognizing patterns. [16] and [17] mentioned the performance of pattern recognition largely depends on the feature extraction approach and classification/learning scheme. Therefore, these two stages will be focus in this study.

Several works on off-line writer identification can be found in previous work. Bensefia[13] proposed writer identification and writer verification by using local features such as graphemes extracted from segmentation of cursive handwriting. He consider these two task fall into the problem of Information Retrieval where, writer identification task has been viewed as a filtering step in finding relevant documents for a user need in a large database and to be use in verification task. It involved segmentation task : connected component are segmented into graphemes; feature extraction task : a set of binary feature is defined with sequential clustering procedure; identification task : finding relevant documents for a user need in large database within the framework of information retrieval.

The work presented in Tapiador[3], defines a handwriting formulation that allows high identification accuracy while minimizing the amount of data used and the sample size. It involved the pre-processing task which undergo the segmentation, normalization and binarization the character using Otsu algorithm; Feature extraction is applied where Gradient-Structural-Concavity features are extracted with geometric properties for features in character shape; identification task which is the method of traditional Nearest Neighbor algorithm is applied.

In the work of He[6], method of texture analysis on Chinese handwriting writer identification was proposed. They regard the global text and single character of Chinese as texture. The tasks that included in this work are pre-processing to create texture image; feature extraction by using the Gabor filter after one texture image are divided into four sub texture image; feature matching by using the Weighted Euclidean Distance classifier.

Shen reported his work in [14] for writer identification which involves no local features with three steps : First, a preprocessing method is employed to normalize script images. Then, 2-D Gabor wavelet technique is developed to extract the global features. Finally K-nearest neighbor (K-NN) classifier is designed to identify the person with the identified handwriting. In the pre-processing stage, it divided into two tasks which are manual and automatic pre-processing. Manual process is to get the noise free image meanwhile the other process is to perform gray scale, normalized image and zooming and segmentation automatically.

Schlapbach in [19] proposed Hidden Markov Model based recognizers for the identification and verifications of person based on text-independent handwriting. It involved pre-processing step which the text lines presented to the recognizers are normalized; feature extraction step where three global features (fraction of black pixels in the window, the center of gravity and the

second order moment and six local features (position of the upper and the lower-most pixel, the number of black-to-white transitions in the window and the fraction of black pixels between the upper and lowermost black pixel) are extracted; recognition step which is Viterbi algorithm is used. Presented with a text line, a recognizer produces a sequence of words together with their log-likelihood scores. Summing up the scores of all words gives us the log-likelihood score of a text line. The log-likelihood scores are sorted in descending order and the input text line is assigned to the writer with the highest ranked score.

3. Artificial Immune System (AIS)

The field of AIS is one of the recent biologically inspired approaches to emerge from computer science. The natural immune system is an adaptive learning system that employs many parallel and complementary mechanisms for defense against foreign pathogens. It is a distributed system, capable of learning to identify previously unseen invaders and remembering what it has learnt. Numerous immune algorithms now exist, based on processes identified within human immune systems.

Biological immune system has intelligent capabilities of detecting or recognizing self/non-self antigen in the body. The primary immune defense, also referred to as innate immunity is the immune mechanism our bodies are born with [20]. If the innate immune system cannot remove the pathogen, then the adaptive (secondary immune response) immune system will take over. This vertebrate immune system exhibits some remarkable properties that mentioned in [21], [22], including:

- Feature extraction to determine unique signature of the antigen.
- Learn to recognize new patterns / antigens.
- Work as distributed patter recognizers.
- Use content-addressable memory to retrieve known pattern / antigens.
- Use of selective proliferation and self-replication for quick recognition and response.
- Eliminate / neutralize the effect of antigens in a systematic fashion.

3.1 AIS in Pattern Recognition

As mentioned before, IS has three mechanisms in recognizing pattern but, this study will only focus on NSA. NSA in AIS has been applied to detect computer viruses [23], tool breakage detection and time-series anomaly detection [24] and network intrusion detection [25], [26] color image classification [27] and creative design classification [28].

The original work by [23] which NSA has been inspirational to almost all the research in the AIS related to computer security [29]. In pattern recognition, most of the researches are also influenced by NSA besides CSA. In [30], author tried to summarize the works on existing models and development of AIS research in the year of 1999 to 2003. From the literature review, it shows that there are still no applications or models are developed for writer identification using NSA in AIS.

3.1.1 Negative Selection Algorithm. The NSA is proposed by Forrest in [23] for various anomaly detection problems. It is inspired by the maturation of T-cells in the thymus gland. NSA uses the property of self/non-self discrimination to detect foreign antigens. In the biological system, this is achieved by T-cells which have receptors on their surface that can detect foreign antigens.

[31] has mentioned that a pseudo random genetic process makes the receptors during the generation of the T-cells. Then they undergo a process of filtering in the thymus where T cells that react against self cells are destroyed and only those do not bind to self cells are allowed to leave thymus. These matured T cells circulate through out the body to protect against foreign antigens. NSA works on similar principles, generating detectors randomly and eliminating the ones that detect self, so that the remaining T cells can detect any non self.

The NSA as summarized by Dasgupta in [31] is as follows:

1) Define self as a collection of strings *S* of finite length *L* that needs to be monitored.
2) Generate a set of detectors *R* each of which fails to match any self string in *S* (Figure 3.2).
3) Monitor *S* for changes by continually matching the detectors in *R* against *S*. If any detector matches, then a change is known to have occurred, because the detectors are designed not to match any of the original strings in *S*.

Figure 1 and Figure 2 show the matching process of detector set with new antigens based on related matching rule. Non-self is detected if there is a match between the antigen and any of the detectors.

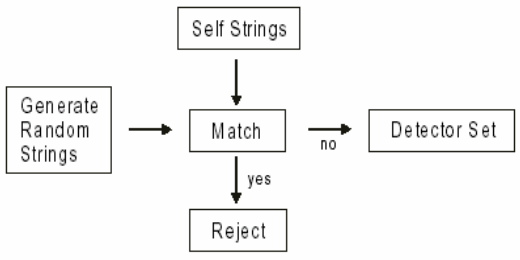

Figure 1: Detector Set Generation

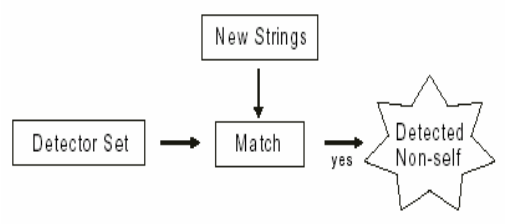

Figure 2 : Self-Nonself Detection by a Detector Set

According to Xiao in [28], the original NSA is not suitable for pattern recognition task. The NSA is originally used to solve change detection problems with only two states defined, either normal or abnormal. In pattern recognition task, negative selection must be extended to multi-state, equivalent to number of classified groups. Xiao in [28] modified the original NSA to be used for pattern recognition in engineering creative design. The modified algorithm is discussed in section 3.2 below. Since this study aimed at pattern matching of handwritten, the modified NSA by Xiao in [28] is adopted. However, the algorithm is customized in hope to increase accuracy of classification.

3.2 AIS Related Work

One such natural system, AIS can be seen as a parallel and distributed adaptive system with many strength capability in recognition, feature extraction, diversity, learning, memory, distributed detection and self regulation. Nasaroui in [32] mentioned that based on the complete capabilities of detection and recognition antigen in the body, an intelligent computational technique has been developed for pattern recognition and data analysis.

AIS has been applied to detect computer viruses [23], tool breakage detection and time-series anomaly detection [24] and network intrusion detection [25],[26], color image classification [27], creative design classification [28], cancer classification [33], learning to detect texture objects [34], character recognition by using CSA [35] and ect.

Sathyanath in [11], proposed a computational implementation of negative selection of immune system along with genetic algorithm (GA) to perform a color image classification task. Detectors are generated by using NSA but, this procedure had the major limitation of generating valid detectors due to its random generated detectors. Hence, GA was explored to improve the random generation detectors.

Xiao in [28], proposed a method based on NSA for pattern recognition in engineering creative design. The modified algorithm by Xiao is as follow:

1) Define self as N sets of strings S_i (the suffix i starts from 1 to N) of limit length
2) Generate N sets of detectors and each should fail to match with members of the pre-classified groups.
3) Present the input pattern to the N sets of detectors respectively. If any match occurs at the i^{th} set of detectors, the input pattern belongs to the corresponding groups and the pattern matching task is finished.

Shin in [33], presented a method for cancer type classification based on micro-array data with the implementation of AIS for ALL(lymphoid precursor) / AML(myeloid precursor). Important aspects in this problem are selection of informative genes (feature selection) and optimization of strength (weight) of each gene. Shin solves the problems by group the ALL training data set as antigen and AML training data set as self-proteins. Classification rules represent antibody, which captures training samples (antigen/self-proteins) when its profile satisfies the condition of the rules. A population of antibody goes through a cycle of invasion by antigen and selective reproduction. Then, a successful antibody will convert into memory cell as ALL/AML class is learned. NSA and CSA were combined to improve the classification capability in this problem.

Zheng in [34], proposed an AIS approach to automatically generate segmentation thresholds and texture filters. It will automatically detect texture object from panchromatic satellite images. CSA is used to learn the texture filters and segmentation thresholds because of its ability to search with optimal solution. Texture objects are regarded as antigens and texture object filters and segmentation thresholds are regarded as antibodies in this approach.

Jennifer in [35], examined the CSA CLONALG over a series of binary character recognition, compared to basic binary matching algorithms. They have made few enhancements to CLONALG algorithms. CLONALG failed to capitalize on the information generated by each clone population. New algorithm of CSA called Clonal Classification (CLONCLAS) has been proposed to improve its performance of classification.

4. A Proposed AIS Framework in Writer Identification

Writer identification has reported by Shen [14] as a typical pattern recognition problem. In our proposed approach, we adopt the feature extraction and classification tasks in process of identifying the writer. It consists of three phases which are feature extraction, training and classification phase as shown in **Figure 3**. However, we omit the pre-processing process such as normalization or thinning process where feature extraction is extracted directly from gray-scale images of

scanned document. Pre-processing process has been shown to improve the image quality but as part of this process some of the original information may be lost [36],[37]. According to Wahab [38], the classical approach which is widely used today, incorporates image-processing steps such as equalization, binarisation, thinning, and so on. However, there are several drawbacks in these approaches such as the loss of valuable data and the inability to differentiate between noise and the expected image. Furthermore, Pervouchine in [18] has stated that the thinning process in pre-processing will destroy the strokeorder information which can be used in handwriting recognition as well as in author identification. Therefore, this author proposed a method of skeletonisation (stroke extraction) of handwritten character image where it is very close to human perception of the original pen tip trajectory where is constructed in three steps (vectorization, merging of skeletal branches, fine tuning of skeleton) directly from the grayscale image. The skeleton is represented as a set of curves, which, in turn, are represented as cubic B-Splines.

There are a few research have been done by directly extracting feature from the gray scale image such as in the work of Wang[37], where features are extracted directly from gray-scale character images for character recognition problem especially in low-quality image; Direct gray-scale minutiae extraction approach has been proposed by Wahab[38] to solve the fingerprint verification problem; Chang [39] present the minutiae detection algorithms in direct gray-scale for low quality fingerprint image where the pre-processing stage of an fingerprint identification system will produces redundant minutiae or even destroys the real minutiae.

In the task of feature extraction, global moments function specifically on United Moment Function will be used. It has been proposed in [40] for shape discrimination with introduced some new formulas of moment invariants that are defined united moments. Global moments function has been used in a variety of image analysis application. A set of moments computed from a digital image generally represents global characteristics of the image shape, and provides a lot of information about different types of geometrical features of the image [41]. Mukundan in [41] also mentioned that the shape characteristics can be further be used to construct feature vectors that are invariant with respect to image translation, rotation and scaling. Hu in [42] first introduced moment invariants based on the methods of algebraic invariants, which were used for automatic character recognition. He reported that recognition schemes based on two-dimensional (2D) moment in variants are position, size and orientation independent and flexible enough to learn any set of pattern.

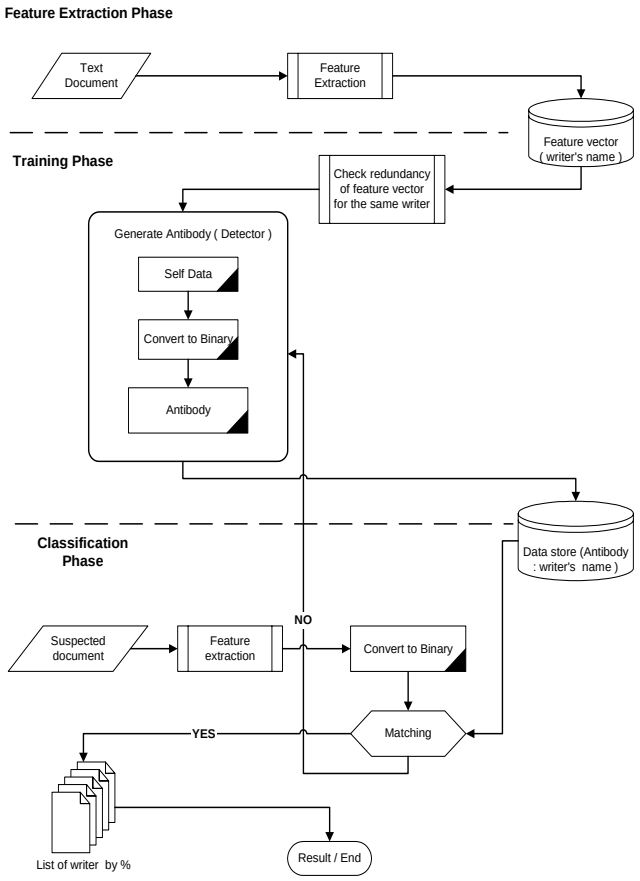

Figure 3 : A Proposed AIS Framework in Writer Identification

In training phase, sets of self data obtained from feature extraction phase are transformed and represented in binary string. No random detectors are generated and compared with self string to determine the antibody. This is because simply by keeping the complement of self string as antibody is enough to cover all detectors possibly generated using random method as implemented in Xiao [28]. The antibody sets are much smaller compared to random method. Random detectors generation has the limitation of generating valid detectors if the size of random generated detectors is small [27]. However, if large number of detectors is generated, it will be time consuming and there is no guarantee that generated detectors are not repeated in the process. The antibodies are generated and stored for matching with antigen in classification phase.

In classification phase, questioned document is extracted and the features are transformed to binary, which are assumed as antigens. These antigens are compared to antibody from the antibody database. If there is no matched, then the antigen will go through the generate antibody process to produce a new data

(memory). The new data are saved to the database. Otherwise, it will be listed as potential writer which will later be sorted by percentage. The highest percentage is claimed as owner of the questioned document.

Initially, the proposed framework is tested on iris data and pendigit. The matching threshold used also influence the results of classification. From **Table 1**, it can be seen that when matching threshold set to 3-5, the accuracy of classification is highest compared to other threshold value. Setting the value of matching threshold too high or too low will decrease the accuracy of classification. If the value is too high, then the matching will be very specific and sensitive. Therefore, unknown samples will be unidentified and might not be matched by any of the detectors (antibodies). Meanwhile, if the matching threshold is set too low, the matching will be very general.

5. Conclusion

This paper gives an overview of pattern recognition specifically on writer identification problem. AIS and NSA have been discussed in general. Related work with AIS in pattern recognition also briefly reviewed. The proposed AIS framework has been described to identify the authorship of handwritten document which is initially tested on iris data and pendigit.

6.References

[1] Plamondon, R. and Srihari, S.N. "On-line and off-line handwriting recognition : A comprehensive survey", Pattern Analysis and Machine Intelligence, IEEE Transactions on Volume: 22 , Issue: 1 , 2000. pp. 63 – 84.

[2] Rohlik, Ondrej. "Handwritten Text Analysis.", University of West West Bohemia, Pilsen.
: Ph.d Dissertation. 2003.

[3] Tapiador, Marino and Sigüenza, Juan A.,"Writer Identification Method Based on Forensic Knowledge". Biometric Authentication: First International Conference, ICBA 2004, Hong Kong, China, July 15-17, 2004. Proceedings pp. 555 – 561.

[4] Srihari, S.N.; Sung-Hyuk Cha and Sangjik Lee; "Establishing handwriting individuality using pattern recognition techniques", Document Analysis and Recognition, 2001. Proceedings. Sixth International Conference on , 10-13 Sept. 2001, Pages:1195 – 1204.

[5] Said, H.E.S.; Tan, T.N. and Baker, K.D. "Writer identification based on handwriting", Pattern Recognition 33, 2000, pp.149-160.

	Iris		Pendigit	
Matching Technique	**Training Data**	**Testing Data**	**Training Data**	**Testing Data**
R-chunk Threshold				
3	100	80	100	83.51
4	100	86.67	100	82.02
5	100	80	100	80.65
6	100	80	100	81.39
7	100	80	100	78.54
8	100	80	100	80.14
9	100	80	100	79.11
Hamming Threshold				
3	**100**	**90**	**100**	**83.88**
4	100	86.67	100	83.42
5	100	86.67	100	82.82
6	**100**	**83.33**	**100**	**82.05**
7	100	86.67	100	79.82
8	100	73.33	100	78.34
9	100	70	100	78.79
R-contiguous Threshold				
3	100	80	100	82.71
4	100	76.67	100	80.66
5	100	80	100	80.57
6	100	76.67	100	81.17
7	100	80	100	78.25
8	100	80	100	80.93
9	100	80	100	81.22
Multiple r-contiguous Threshold				
3	100	73.33	100	74.11
4	100	73.33	100	74.13
5	100	70	100	74.76
6	100	70	100	74.62
7	100	66.67	100	74.02
8	100	63	100	74.62
9	100	63.33	100	75.45

Table 1 : Results of Different Matching Rules for Iris Data and Pendigit

[6] HE, Z.Y.; and Tang, Y.Y. "Chinese handwriting-based writer identification by texture analysis". Machine Learning and Cybernetics, 2004. Proceedings of 2004 International Conference on Volume 6, 26-29 Aug. 2004 Page(s):3488 - 3491 vol.6.

[7] de Castro, L.N. and Timmis, J.I. “Artificial immune systems as a novel soft computing paradigm”. Soft Computing Journal. 2003. 7: 526-544.
[8] de Castro, L. N. and Timmis, J. I. "Artificial Immune Systems: A Novel Paradigm to Pattern Recognition", Artificial Neural Networks in Pattern Recognition , J. M. Corchado, L. Alonso, and C. Fyfe (eds.), SOCO-2002, University of Paisley, UK, pp. 67-84.

[9] Olfa Nasaroui, Fabio Gonzalez, and Dipankar Dasgupta. “The Fuzzy Artificial Immune System: Motivations, Basic Concepts, and Application to Clustering and Web Profiling”. IEEE International Conference on Fuzzy Systems. IEEE World Congress on Computational Intelligence, Hawaii. 2002. pp. 12-17.

[10] de Castro, L. N. and Von Zuben, F. J. "Artificial Immune Systems: Part II – A Survey of Applications", Technical Report – RT DCA 02/00, 2000. pp. 65.

[11] Sathyanath,S. and Sahin, F. “An AIS Approach to a Color Image Classification Problem in a Real Time Industrial Application”. IEEE International Conference on Systems, Man, and Cybernetics. 4. 7-10. 2001. pp.2285-2290. Tucson, AZ USA: IEEE.

[12] Liu, Cheng-Lin, Nakashima, Kazuki, , Hiroshi and Fujisawa, Hiromichi. “Handwritten digit recognition: benchmarking of state-of-the-art techniques”, Pattern Recognition, 2003. Volume 36, Issue 10. pp 2271-2285.

[13] Bensefia, A.; Paquet, T. and Heutte, L. “A writer identification and verification system”, Pattern Recognition Letters, In Press, Corrected Proof, Available online 23 May 2005.

[14] Shen, Cong; Ruan, Xiao-Gang and Mao, Tian-Lu. “Writer identification using Gabor wavelet”, Intelligent Control and Automation, 2002. Proceedings of the 4th World Congress on Volume 3, 10-14 June 2002 Page(s):2061 - 2064 vol.3.

[15] Bensefia, A.; Nosary, A.; Paquet, T and Heutte, L.; “Writer identification by writer's invariants”, Frontiers in Handwriting Recognition, 2002. Proceedings. Eighth International Workshop on 6-8 Aug. 2002 Page(s):274 – 279.

[16] Cheng-Lin Liu, Kazuki Nakashima, Hiroshi Sako and Hiromichi Fujisawa “Handwritten digit recognition: benchmarking of state-of-the-art techniques”, Pattern Recognition, 2003. Volume 36, Issue 10. pp 2271-2285.

[17] Cheng-Lin Liu, Kazuki Nakashima, Hiroshi Sako and Hiromichi Fujisawa. “Handwritten digit recognition: investigation of normalization and feature extraction techniques ”, Pattern Recognition, Volume 37, Issue 2. 2004. pp. 265-279.
[18] Pervouchine, V., Leedham, G and Melikhov, K. “Handwritten character skeletonisation for forensic document analysis”, Proceedings of the 2005 ACM symposium on Applied computing, March 13–17, 2005, Santa Fe, New Mexico, USA.

[19] Schlapbach, Andreas and Bunke, Horst. “Using HMM Based Recognizers for Writer Identification and Verification”, In Proc. 9th Int. Workshop on Frontiers in Handwriting Recognition, pages 167–172, 2004. Kokubunji, Tokyo, Japan, 26.–29. October 2004.

[20] Janeway, A. “How the Immune System Recognizes Invaders”. Scientific American. 1993. Pp 41-47.

[21] Dasgupta, D. and Nino, F. “A comparison of negative and positive selection algorithms in novel pattern detection”, Systems, Man, and Cybernetics, 2000 IEEE International Conference on , Volume: 1 , 8-11 Oct. 2000, Pages:125 - 130 vol.1.

[22] J.D. Farmer, N.H. Packard and A.S Perelson. “ The immune system, adaptation and machine learning”, Physica D, 1996. 22 : 187-204.

[23] Forrest, S., Perelson, A.S., Allen, L. and Cherukuri, R. “Self-nonself discrimination in a computer”. Proceedings of IEEE Symposium on Research in Security and Privacy, 16-18. 1994 May pp. 202-212. Oakland, CA USA: IEEE.

[24] Dasgupta, D. “An Overview of Artificial Immune Systems and Their Applications”, Berlin: Springer-Verlag. 3-23. 1998.

[25] Hofmeyr, S. “An Immunological Model of Distributed Detection and Its Application to Computer Security”. University of New Mexico: Phd Thesis. 1999.

[26] Hofmeyr, S. and Forrest, S. “Architecture for an Artificial Immune System”. Evolutionary Computation, 2000. **7**(1). 45-68.

[27] Sathyanath, S. and Sahin, F. “An AIS Approach to a Color Image Classification Problem in a Real Time Industrial Application”. IEEE International Conference on Systems, Man, and Cybernetics. 4. 710. 2001. pp.2285-2290. Tucson, AZ USA: IEEE.

[28] Xiao, R. B., Wang, L. and Liu, Y. “A Framework of AIS Based Pattern Classification and Matching for Engineering Creative Design”. Proceedings of the First

International Conference on Machine Learning and Cybernetics. Beijing: IEEE. 2002. pp. 1554-1558.

[29] Ayara, M., Timmis, J., de Lemos, R. de Castro, L. N. and Duncan, R. "Negative Selection: How to Generate Detectors", Proc. of ICARIS (International Conference on Artificial Immune Systems), 2002. pp. 89-98.

[30] Dasgupta and Gonzalez, "Artificial Immune System(AIS) Research in the Last Five Years", International Conference on Avaluationary Computation Conference (CEC), Canbara, Australia. 2003.

[31] Dasgupta, D. "Artificial Immune Systems and Their Applications". Germany: Springer-Verlag. 1999.

[32] Nasaroui, Gonzalez & Dasgupta. "The fuzzy Artificial Immune System : Motivation, Basic Concepts and Application to Clustering and Web Profiling", IEEE, 0-7803-7280-8. 2002.

[33] Shin Ando and Hitoshi Iba. "Artificial Immune System for Classification of Cancer", EvoWorkshops 2003. LNCS 2611, pp. 1–10.

[34] Zheng, Hong, Zhang, Jingxin and Nahavandi, Saeid. "Learning to detect texture objects by artificial immune approaches Future Generation Computer Systems, Volume 20, Issue 7, 1. 2004. Pp. 1197-1208.

[35] Jennifer A. White and Simon M. Garrett. "Improved Pattern Recognition with Artificial Clonal Selection?'. ICARIS 2003, LNCS 2787, 2003. pp. 181–193.

[36] Dehkordi, M.E., Sherkat, N. and Allen, T. "Handwriting style classification". International Journal on Document Analysis and Recognition, Volume 6, Number 1, Pages: 55 - 74, 2003.

[37] Wang, X., Ding, X. and Liu, C. "Gabor filters-based feature extraction for character recognition", Pattern Recognition, v 38, n 3, March, 2005, p 369-379.

[38] Wahab, A., Tan, E. C. and Jonatan, A. "Direct Gray-Scale Minutiae Extraction", Biometric Authentication: First International Conference, ICBA 2004, Hong Kong, China, July 15-17, 2004.

[39] Chang, J. H. and Fan, K. C. "Fingerprint ridge allocation in direct gray-scale domain", Pattern Recognition, Volume 34, Issue 10, October 2001, Pages 1907-1925.

[40] Frosini G, Lazzerini B, Maggiore A and Marcelloni F. "A Fuzzy Classification Based System for Handwritten Character Recognition", IEEE, 0-7803-4316-6, 1998. pp. 61-65.

[41] Impedovo, S. "Fundementals in Handwritting Recognition", Springer-Verlag, Berlin. 1994.

[42] Gunter, Simon and Bunke, Horst. "Creation of Classifier Esembler for Handwritten Word Recognition Using Feature Selection Algorithms", IEEE International Workshop on Frontiers in Handwriting Recognition., 2002.