GAZİANTEP UNIVERSITY GRADUATE
SCHOOL OF NATURAL & APPLIED
SCIENCES

DESIGN AND IMPLEMENTATION OF BIOMETRIC RECOGNITION USING OFF-LINE SIGNATURE ANALYSIS

Ph.D. THESIS
IN
MECHANICAL ENGINEERING

BY
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Design and Implementation of Biometric Recognition Using Off-Line Signature Analysis

Ph.D. Thesis
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Supervisor
Prof. Dr. L. Canan DÜLGER

by

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

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ABSTRACT

DESIGN AND IMPLEMENTATION OF BIOMETRIC RECOGNITION USING OFF-LINE SIGNATURE ANALYSIS

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Analysis of signature is a widely used and developed area of research for personal verification. A Software is introduced to solve problems related with verification of individuals by using off-line signature verification which is a branch of biometric verification in the first part of study. The presented signature verification system includes image processing techniques and other mathematical tools in its structure. The proposed system is composed of five sub-systems; data entry, preprocessing, feature extraction, comparison and performance evaluation. The developed system tries to determine the originality of the signature mathematically. The technique is based on Neural Network (NN) approach trained with Particle Swarm Optimization (PSO) algorithm. To test the performance of the proposed algorithm, three types of forgeries; random, unskilled and skilled are examined and the experimental results are presented with verification accuracy and statistical figures.

Design and construction of a questioned document investigation device is also included in the second part of study. Varieties of document examinations are facilitated by special lightening features and lens systems. This questioned document device can perhaps be one example of an optomechatronics system which includes cameras, different kind of light sources (ultraviolet and infrared) and lenses. Using modern spectral imaging technology it has been possible to detect very small differences available on inks and papers. Image Processing Software for Questioned Document (*IMPQD*) is also used to control of both the designed device and perform signature verification using the image of document and an available signature database.

Key Words: Off-line Signature Verification, PSO, NN, Biometric, Optomechatronics, Questioned Documents

ÖZET

ÇEVRİM DIŞI İMZA ANALİZİ KULLANILARAK BİYOMETRİK DOĞRULAMA TASARIMI VE UYGULAMASI

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İmza analizi kişisel doğrulama için oldukça geniş bir alanda kullanılan ve gelişmekte olan bir araştırma alanına sahiptir. Çalışmanın ilk kısmında, biyometrik doğrulamanın bir kolu olan çevrim dışı imza analizi kullanılarak bireyin doğrulanmasına yönelik sorunların çözümüne yardımcı olacak bir yazılım tanıtılmıştır. Sunulan imza doğrulama sistemi, görüntü işleme tekniklerini ve diğer matematiksel araçları bünyesinde barındırmaktadır. Önerilen sistem; veri toplama, ön işleme, özelliklerini çıkarma, karşılaştırma ve performans değerlendirmenin yapıldığı beş alt sistemden oluşmaktadır. Geliştirilen sistem imzanın orijinalitesini matematiksel olarak belirlemeye çalışılmaktadır. Kullanılan teknik yapay sinir ağlarının (YSA) eğitiminde parçacık sürü optimizasyonunu (PSO) temel almaktadır. Önerilen algoritmanın denenmesi için gelişigüzel, yeteneksiz ve yetenekli olmak üzere üç çeşit taklit imza kullanılmış ve deneysel sonuçlar doğrulama değerleri ve istatistiksel ölçütler ile sunulmuştur.

Çalışmanın ikinci kısmı ise optomekatronik olarak tanımlanabilen bir sistem olan şüpheli döküman inceleme cihazının tasarlanmasını ve kullanımını içermektedir. Belge incelemelerinde özellikli ışık kaynakları ve lensler kullanılmasıyla sınıflandırılmaktadır. Şüpheli belge incelemede kullanılan cihaz kameraların, farklı ışık kaynaklarının (Mor ötesi ve Kızıl ötesi) ve lenslerin kullanıldığı optomekatronik bir sistem örneği olarak verilebilir. Modern görüntü alma teknolojisi kullanılarak mürekkep ve kağıt arasındaki en ufak farklılıklar tanılanabilmektedir. Tasarlanan cihazın denetiminde ve imza tanılamada ise belge imgesinin ve mevcut imza verilerinin işlenmesi için hazırlanan bilgisayar yazılımı 'Şüpheli Belge için Görüntü Analizi Yazılımı' (IMPQD) programı kullanılmıştır.

Anahtar Kelimeler: Çevrim Dışı İmza Analizi, PSO, YSA, Biyometrik, Optomekatronik, Şüpheli Belgeler

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Most of all, thanks to my wife, G. Sena DAŞ for motivating me to pursue research and for guiding me through each and every step along the way, who brought me peace, made me smile, and gave me strength all the way through. This work is dedicated to her and to my son Ö. Görkem.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Analysis of signature is a widely used and developed area of research for personal verification. In this study, a software is introduced to solve problems related with verification of individuals by using off-line signature verification which is a branch of biometric verification. Design and construction of the questioned document investigation device is also performed. This device is one example for an optomechatronic system. Optomechatronic devices can be defined as systems which include cameras, different kind of light sources, and lenses in mechatronic concept.

1.2 Motivation of The Thesis

Biometrics is the science and technology of authentication by measuring the person's physiological or behavioural features, such as fingerprint, iris & retina scanning, face recognition, signature and handwriting, voice and speech recognition [1]. The term is derived from the Greek words "*bios*" for life and "*metron*" for measure. Biometrics also refers to an entirely different field, which is known as Biostatistics. It concerns the development of statistical and mathematical methods applicable to data analysis problems in the biological sciences. In information technology (IT), biometrics is the utilization of biological characteristics (face, iris, and fingerprint) or behavioural traits [2] (signature, voice) for identity verification of an individual. Biometrics are used in two major ways as identification and verification. Identification means to determine who a person is. However, verification is simply to determine for a person says who she/he is.

Biometric authentication is gaining popularity as a more trustable alternative to password based security systems as it is relatively hard to be forgotten, stolen, or guessed [3].

Biometric Technologies (BT) are important multidisciplinary research areas targeted at automatic identity verification applications. Verification processes especially based on behaviour do not show 100 % verification due to some environmental and personal differences in BT. Therefore, researchers have employed different approaches such as pattern recognition, image processing and analysis for verification processes.

Biometric technologies can be described using two main problem definitions; direct problem and inverse problem which can be seen in Table 1.1.

Table 1.1 Problem and Inverse Problem definitions

Problem	Inverse Problem
Signature Identification	Signature Forgery
Handwriting charac. recog.	Handwritten text forgery
Voice and speech recognition	Voice and speech imitation
Face recognition	Face reconstruction
Iris and retina recognition	Iris and retina image recons.
Fingerprint identification	Fingerprint imitation
Hand geometry recog.	Hand geo. recons. and imit.

The devices used in biometric technologies are one of the existing parts of optomechatronics, which means that devices and technologies used in biometrics consist of the field of optomechatronics. General development of the optomechatronics can be seen in Figure 1.1.

Optomechatronic is a technology integrated with the optical, mechanical, electrical, and electronic technologies. Figure 1.2 illustrates the fundamental functions to produce optomechatronic systems [4]. In the centre of the figure, optical elements are shown, while mechatronic elements and artificial intelligence are listed on its periphery. These enabling technologies are integrated to form a few main sections which are actuators, sensors, control techniques, signal processing, and decision making systems to direct the technology. An example such a system is given here a '*questioned document investigation device*'. The design of such a device requires use of a CCD camera and X-Y table, controller, illumination, filters, software and integrates them for proper functioning. This kind of interaction between all of the modules is quite common in optomechatronics systems.

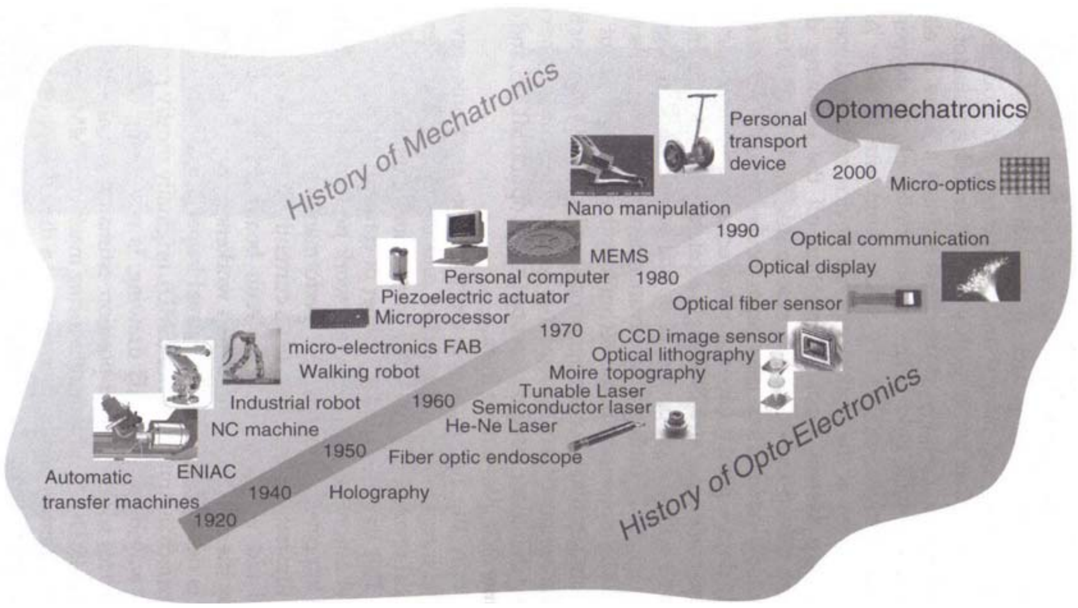


Figure 1.1 Historical Background of Optomechatronics[4].

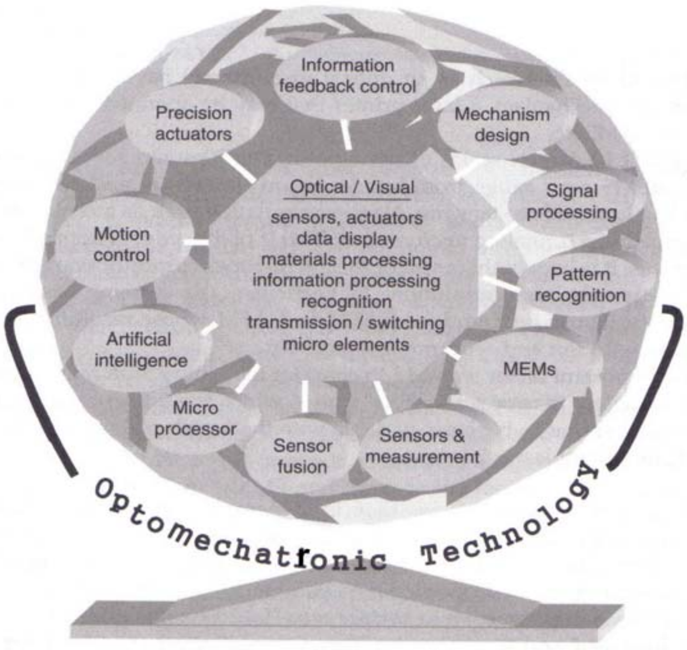


Figure 1.2 Technologies required for optomechatronic system[4]

1.3 Statement of the Problem

Signature which is an important authentication data in forensic science is a behavioural biometric. Signature always appears on letters, cheques, and all legal documents or on other signed papers. Signature is not based on the physical properties, such as fingerprint or face, of the individual. Moreover, an individual's signature may change over time and it is not nearly as unique or difficult to forge as iris patterns or fingerprints. Each writer reproduces a particular pattern during signing. Variations simply occur in size, alignment, connections and sometimes in forms of letters. Variability can be observed in signatures according to country, age, time, habits, psychological or mental state [5]. However, signature's widespread acceptance by the public makes it more suitable for certain lower-security authentication needs.

Signature imitation is one of the typical inverse problems of graphology. Thus, signature verification (SV) has a special importance in BT. Signature verification is a widely studied area of research in the literature. SV is the process of determining an original signature from a forgery-based one after the completion of a verification process. There are two main approaches for signature verification according to the available data in the input; ***on-line SV*** and ***off-line SV*** in the literature**.**

The first approach is ***on-line SV*** which uses an electronic tablet and a stylus connected to a computer to extract information about a signature. This approach takes dynamic information like; pressure, velocity, acceleration, number of strokes, sequence of strokes and etc. The other approach is ***off-line SV*** where stable dynamic variations are not used for verification purpose. It is useful in automatic verification of signatures found on bank checks and documents. It uses an optical scanner to obtain handwriting data on paper. Off-line SV problem is more challenging than on-line since off-line signatures have still been used in many real world applications. Recognition in an off-line system is more difficult than in on-line systems; because of highly stylish and unconventional writing styles in which it is difficult to copy signature strokes. Some of the variations of the signature of non-repetitive nature are due to age, illness, geographic location and emotional state of the people [6].

Bonaparte's signatures can be given a good example for the variations on all of above in Figure 1.3.

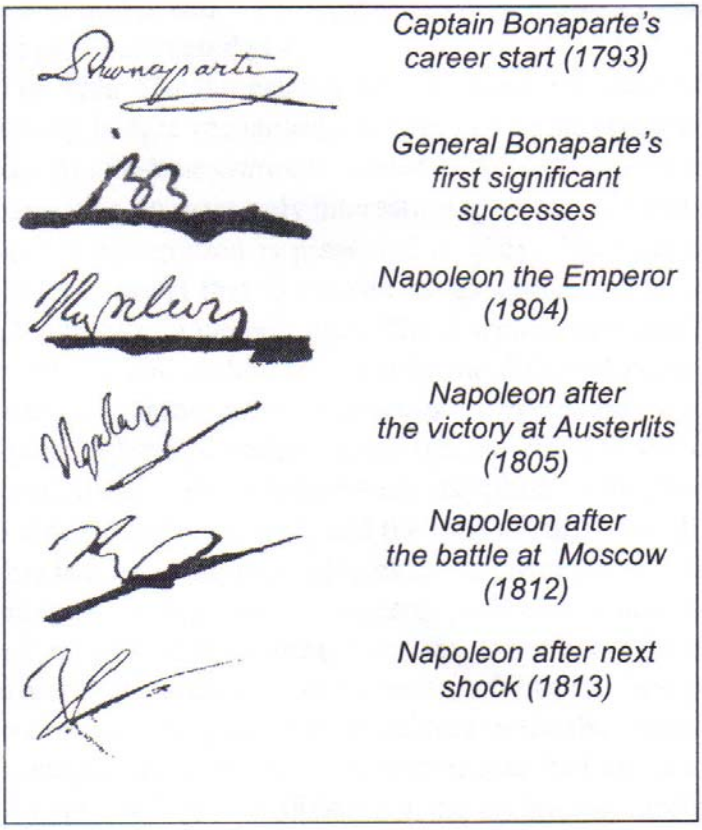
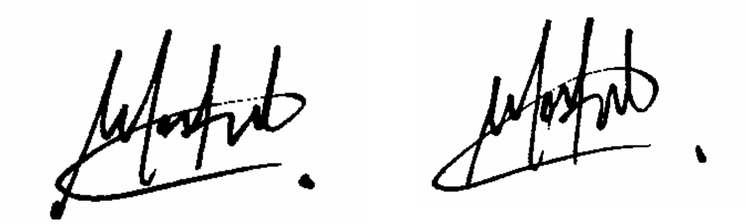


Figure 1.3 Example for Bonaparte's Signature [6]

A human being is able to compare two signatures and is able to make a statement about their similarities and differences. Initial attempts to imitate this ability using a computer program confined themselves to a purely 'graphical' comparison of two pictures (pattern matching). However, it is apparent that this method does not produce satisfactory results with signatures, as they are inherently aberrant and dependent on the tools used to produce them. Moreover, there are differences that will always exist due to the natural variation between two signatures from the same person.

Handwritten signatures are captured with a scanner or a camera then saved and stored in a digitized form. Consequently, a writer will never produce exactly the same signature in the second time. Complications in the process of distinguishing a genuine signature from a forged one arise due to the size and location variations within a person's signature [7]. An example for signature variations performed by same person is given in Figure 1.4.



Signature 1 Signature 2

Figure 1.4 Signature Variations performed by the same person

The most important characteristics of the signatures which are noticed by examiners are given in Figure 1.5. These characteristics are crossings, upstrokes, enclosed areas, curves and loops. They have to be taken into consideration before each examination

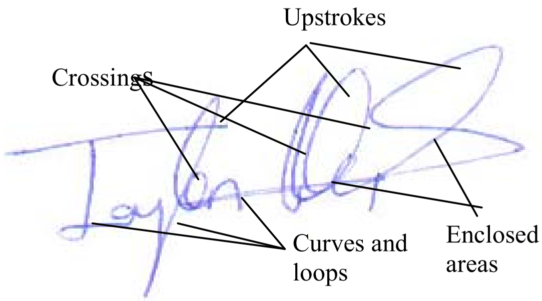


Figure 1.5 Characteristics of the Signature

Researchers have tried to address the issues [7] which are important on this subject nearly 25 years of time. Since then, many other new techniques have been developed and these new techniques have continued to improve throughout the years. Nevertheless, as of today, there is still no definite solution that can completely solve the signature verification problem. There is no system available which can verify signatures with 100% accuracy at present applications.

1.4 The Purpose and Contribution of the thesis

In this study, already existing and also new approaches have been performed for SV process. The questioned document investigation is also studied with integration of SV tools. The main purpose and the contribution of this thesis are to develop a reliable SV toolbox based on the verification of off-line signatures with a new proposed algorithm. Information related with SV toolbox and algorithm is given below. A questioned document device is offered that can be used for both the SV and forensic purposes. Both are still widely used in many areas in society by validating cheques, financial and legal documents. Different ink test, hologram applications, invisible inks and destruction of the documents are the main applications of the forensic purposes for questioned document examination by experts. General overview of this thesis can be given as in Figure1.6.

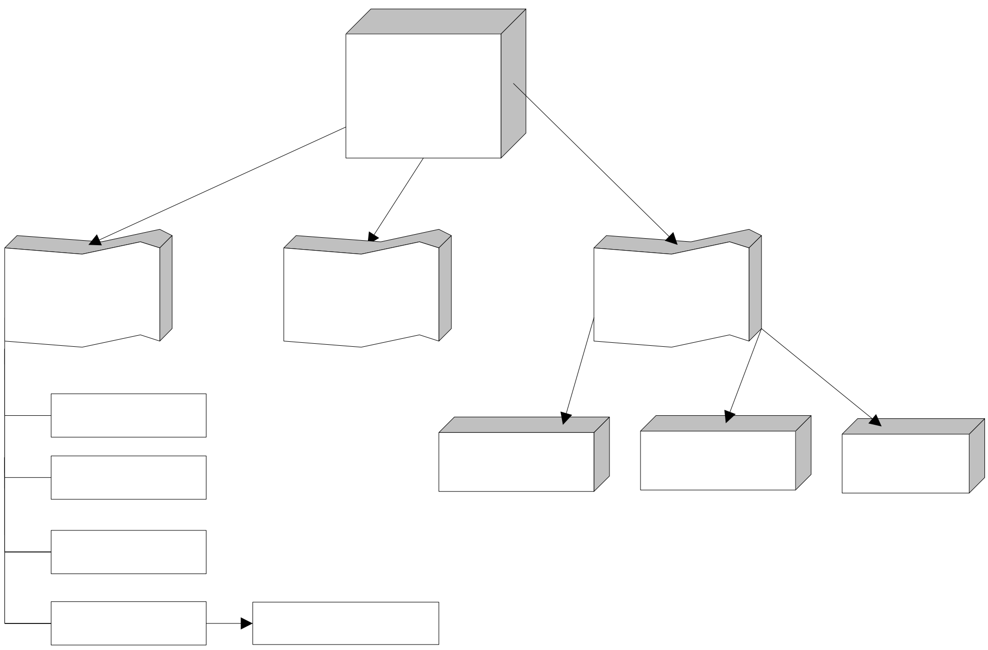


Figure 1.6 Overview of the study

What has been done in this study can be summarized as:

- Questioned document device is designed and constructed. Direction of the lightening can be moved on the documents which can supply the angle of lightening and the image acquisition is affected with this application. This means that illumination flexibility is provided to the system. This is one of the originality involved in this thesis.

- Signature verification toolbox is included on the software which is an original contribution for the questioned document investigation. Two different applications are combined in a toolbox. User can apply the software independent from the device.

- Graphical User Interface (GUI) program, IMPQD (Image Processing for Questioned Document), which includes the control of both mechanical (x-y table, CCD camera, and different light sources) and computational processes (image processing and SV toolbox).

- Grupo de Procesado Digital de Senales (GPDS) database is used. New and available feature extractions are then used for the distinctive features of handwritten signatures. Centre of gravity, distances and angles are calculated for each signature in database. They are normalized from each one of the local grids and used for giving final decision on its originality at the end.

- A verification approach NN with PSO, so called (PSO-NN) algorithm is developed to recognize the genuine signatures from the forgeries. PSO algorithm is adopted to learning part of the NN. PSO is a metaheauristic algorithm generally adopted to increase abilities of the systems.

- The developed SV toolbox uses five steps; data acquisition, pre-processing, feature extraction, comparison process and performance evaluation for the verification process. The main steps of the SV system are shown in Fig 1.7. The signatures are scanned and extracted from the document. These signatures are then pre-processed to remove spurious noises. Then feature extraction process is performed the specific characteristics extracted from the image. Two different data sets are prepared for *'forgery'* and *'genuine'* signatures. The performance of the method is evaluated on previously prepared signature database. These databases are both used for the comparison and verification processes. Finally, a decision to accept or reject the test signature is made on the basis of the decision threshold which has to be achieved between false acceptance rate (FAR) and false rejection rate (FRR). Finally, statistical analysis of the results are performed

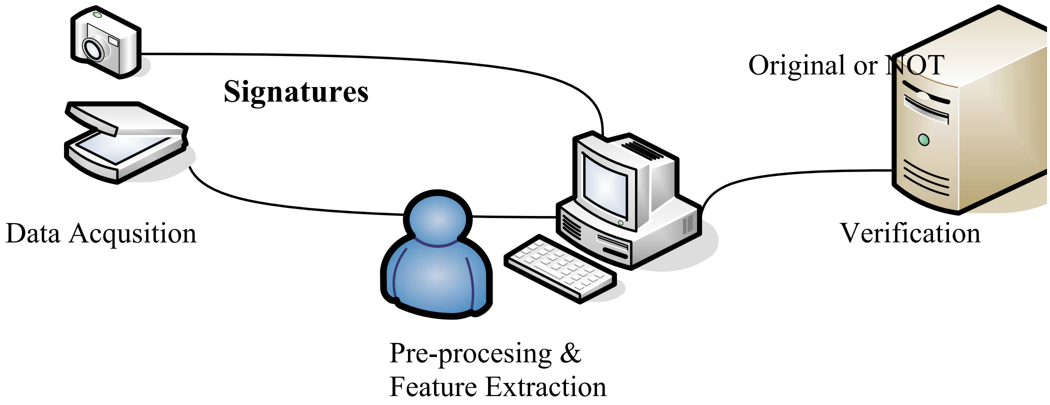


Figure 1.7 The Process of Signature Verification

The definitions on terminology are included in the related chapters for the signature verification.

1.5. Structure of the thesis

This study includes seven chapters. Introduction on biometric technologies is given at the beginning. The study is proceeded with literature survey in this area. Then, mathematical background is given for applied methods in related part. Software and SV toolbox are introduced with the help of mathematical explanations. Design criteria and construction of the questioned document device are explained with application examples. Finally discussion, conclusion and a few suggestions for future work are included.

Chapter 1 is related with the fundamentals of biometrics, biometric technologies, questioned document investigation and signature verification. Types of the verification methods are given. Then, signature verification is introduced with verification processes. Statement of the problem is defined. The proposed method, PSO-NN and contribution of the thesis are included.

Chapter 2 reviews a detailed literature survey on the off-line signature verification. The previously used verification algorithms, different feature extraction methods have been presented with pre-processing. Additionally, an overview on algorithm PSO and inspiration of this thesis are represented in this chapter.

Chapter 3 provides the mathematical background for the proposed method; Particle Swarm Optimization (PSO), Neural network (NN) and combination of both as PSO-NN. Initially, Swarm Intelligence (SI) is introduced. Theory of the PSO and its application areas are also described. The proposed method, PSO-NN is explained and its structure is given. Applications of the verification processes are presented.

Chapter 4 illustrates the Image Processing for Questioned Document (IMPQD) software and SV toolbox which are introduced. Specifications of the IMPQD are given in detail. Preparations of the Signatures with toolbox, Data acquisition, Pre-processing, Feature extraction and Verification parts are explained. Thus basically this chapter deals with methods for analysing images to see all of the details involved.

In Chapter 5, A literature survey in questioned documents is presented. The questioned document investigation device is then introduced and illustrated. Its design issues about illumination, filters and other parts of device are given. A brief overview of on document investigation in use is also presented in the same chapter.

Chapter 6 represents the application of the proposed SV algorithm on random, unskilled and skilled forgeries. Experimental results and application procedure are also included. Statistical analysis is performed by using Chi-square (χ^2) method. Verification results are presented with histogram plots and probability measures.

Performance of the device and results are utilized in Chapter 7. The present study is concluded with sections '*observations on off-line SV* 'and '*observations on questioned documents*'. Finally, the thesis is ended with a section on suggestions for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, signature verification literature is reviewed by looking at verification algorithms, pre-processing techniques and extraction processes. Since the main concentration of this thesis is to propose a new verification method for the signature verification, the studies in the literature are classified according to the verification algorithms used in general.

Up to date many signature verification algorithms have been used in the field of off-line signature verification. The most appealing approaches among these studies are the ones based on Neural Networks (NN) and Hidden Markov Models (HMM). Thus, the literature is examined and classified with three main headings; namely, Studies using Neural Networks, Studies using Hidden Markov Models, Studies using other approaches.

2.2 Survey on Studies Using Neural Network (NN)

In this section, literature review is searched according to the neural network learning algorithms and methods used in verification.

Sabourin and Drouhard [8] have described a handwritten SV system. They have applied directional probability density function (PDF) and feed forward NN with back-propagation (BP) learning to random signatures in verification process.

NN algorithm is described by See and Seng [3] to analyse and obtain the optimal values of factors such as learning rates, skilled forgeries and pre-processing of images which affect the performance and also accuracy of a SV system. A modified model of BP has been used to reduce the learning time of the system.

Drouhard et al. [9] have improved PDF and BP-NN by using the global classification error in memorization and generalization. Following, Pottier and Burel [10] have used multi layer perceptron for identification and authentification of handwritten signatures with a connectionist approach.

Murshed et al. [11] have been presented a Fuzzy Artmap NN trained only genuine signatures based on off-line SV system.

Zhou and Quek [12] have developed an automatic fuzzy NN driven SV system. In a different study multi layer perceptrons are again used by Dehghan and Fathi [13] who presented multiple multi layer perceptron NN modules trained with global features cooperating in taking an off-line SV.

Huang and Yan. [14] have studied on off-line SV based on geometric feature extraction and NN classification. Baltzakis and Papamarkos [15] have used a two stage NN for off-line SV. In the first step, one has taken the decisions from NN and Euclidean distance classifier. The second one has combined all decisions by using a radial- base function NN.

Santos et al. [16] have proposed to reduce the number of signature samples required by each writer in the training phase of off-line SV. A set of graphometric features and NN classifier have been used for this reason.

Sabourin et al. [17-18] have studied on a local granulometric size distributions. A signature was centred on to a grid of rectangular retinas, which were excited 36 by the signature's trajectory pixels at that location. Granulometric size distribution was used as the shape descriptors of each retina, where granulometry is the result of a set of morphological openings. Finally, a feature vector of dimension equal to a number of retinas was used by k-NN classifier to detect random forgeries. The system's performance was evaluated using the same test data set and the best result reported to be a 0.02% of equal error rate. Although very good results were obtained from both systems, they both assume that all signatures were of similar size, and the corresponding strokes of the signatures fell into approximately the same retinas.

Velez et al. [19] have studied on a new robust technique for the off-line signature verification problems in practical real conditions have been presented. The technique was based on the use of compression neural networks, and in the automatic generation of the trained set from only one signature for each writer. The study incorporated with a new kind of acceptance and rejection rule, which was based on the similarity between sub images or positional cuttings of a test signature and the corresponding representation stored in the class compression network.

Marinai et al. [20] have studied on the survey of artificial neural networks applications on off-line document image processing, where connectionist based approach had been applied. They have discussed similarities and differences between approaches belonging to different classes. The importance of the learning algorithms and available approaches has been provided in the study.

Surveys on studies using NN are summarized in Table 2.1 to insure a clear following on the subject.

2.3 Survey on Studies Using Hidden Markov Model (HMM)

Hidden Markov Model is one of the used verification algorithm which is adapted in off-line SV. The detailed literature review is included in this section.

Igarza et al. [21] have presented dynamic methods of application for off-line SV. Left to Right Hidden Markov Model (HMM) has been developed and tested over a skilled forgeries database.

Coetzer et al. [22] have presented off-line SV system using the discrete radon transform and a HMM. Global features have been adopted for robustness of the algorithm.

Justino et al. [23] have compared performance of Support Vector Machine (SVM) and HMM classifiers in off-line SV. The SVM was given a new classification technique in the field of statistical learning theory.

Rigoll and Kosmala [24] have been studied on an extensive investigation of various HMM-based techniques for comparison of on-line and off-line signature verification. Different feature extraction methods and HMM topologies have been compared in order to obtain an optimized high performance system for both on-line and off-line signature verification.

Surveys on studies using HMM's are summarized in Table 2.2 according to years and other details included.

2.4 Survey on Studies Using Other approaches

The other studies related with verification methods are reviewed in this section. Bayesian, Takagi-Sugeno Fuzzy model, geometrical approach and colour code imaging are some of the examples used in verification process.

Lee and Pan [25] have proposed a new approach for offline tracing and representation of signatures. Hierarchical decision making and heuristic rules were involved rules to their approach for tracing.

Fang et al. [26] have proposed an off-line SV method by using tracking of feature and stroke positions of 1-dimensional and 2-dimensional signature patterns.

Ando and Nakajima [27] have proposed a new method for off-line SV that extracts local individual peculiarities from the parts of a signature and used them for verification.

Yusof and Madasu [28]; Hanmandlu et al.[29] have used Takagi-Sugeno (TS) Fuzzy model for SV and forgery detection. They have developed an automatic SV system for bank check verification and auto teller machine (ATM) access.

Wan et al. [30] have presented an off-line SV system that only requires the genuine signatures of a new user without simple forgeries. Hou et al.[6] have also presented survey on off-line SV based on types of forgeries, features and verification systems.

Fasquel and Buynooghe [31] have studied on a hybrid opto-electronic method for the fast automatic verification of handwritten signatures. Image transforms and inter-correlations have been computed simultaneously by using a high speed optical correlator.

Kalera et al. [32] have described a novel approach for SV and identification in an off-line environment based on a quasi-multiresolution technique using gradient, structural and concavity features for extraction.

Ferrer et al. [33] have presented a set of geometric signature features for off-line SV based on the description of the signature envelope and the interior stroke distribution in polar and Cartesian coordinates.

Shihari et al. [34] have discussed the individuality of handwriting, pre-processing and interactive tools of forensic document examination. A statistical model for writer verification and application of the model to SV has been represented.

Kulkarni [35] have applied colour code image processing algorithm for signature recognition. The method uses morphological operations and red, green, blue colour threshold values for recognition.

McKeague [36] has been studied a Bayesian model for off-line signature verification involved the representation of a signature through its curvature has been developed. The prior model was made use of a spatial point process for specified the knots in an approximation restricted to a buffer region close to a template curvature, along with an independent time warping mechanism.

Mizukami et al. [37] have been provided an off-line signature verification system based on a displacement extraction method that has been used for comparing questionable signature with a corresponding authentic one.

Sabourin et al. [38] were based on shape matrices which were used as a mixed shape feature for signature verification. Mixed shape feature was actually a global feature, in calculation of which positions of local features were taken into account. Best results of 0.84% equal error rate were reported using a test data set of 800 signatures. Shape matrices were previously used for planar shape representation of industrial parts and machine printed characters.

Allgrove and Fairhurst [39] have discussed the analysis of the variations in signing style. In addition to the information was available in the reference model data has been used to characterise the consistency of individual signing styles, with the aim of providing contextual information to aid the final decision on the acceptability of a test signature.

Guo [40] has studied a forgery detection of off-line signatures by local correspondence. Differences between online and off-line signatures have been also given in the study. Types of signatures, matching classifications and offline verification have been embedded at the stroke level. Finally experiments on random, skilled and simple forgery detection were illustrated.

Surveys on the other approaches are summarized in Table 2.3 with the results obtained in each study.

2.5 Remarks on Literature Survey

According to the literature survey and the development of biometric systems, studies on SV are continuously improving. The reason for this percentage of the verification or identification rates is not accepted as sufficient enough. In all studies, success is given with different measures. Since the databases and the methods are different, it is nearly impossible to say a exact success on the verification results obtained.. In this survey, it is seen that verification part has a great importance for signature. Available verification techniques have been mostly tried on the *'random'* and '*unskilled forgeries*'. The critical problem of SV is to distinguish the skilled forgery from the genuine one. In general, varying successes are obtained in the problem of forgery detection. SV is preferably accepted in terms of collectability and acceptability. There is no need for a special equipment and device to collect a signature. There is no doubt about its acceptability in all legal documents in worldwide. Conclusively, many real-world problems are solved by application of evolutionary algorithms (EA).

In recent years, evolutionary computation algorithms are included in the part of artificial intelligence. Some of them are based on swarm intelligence, like Ant colony optimization, Bees algorithm, PSO and etc. PSO is applied to an off-line SV problem and chosen for training of NN instead of other learning algorithms which are used previously. A new technique PSO-NN is proposed and performed for the verification of off-line signatures here in. PSO has been successfully applied to a range of engineering problem. It has seen that the most potential application areas are pattern recognition, biological system modeling, robotic applications, simulations and identification. Additionally, PSO has an advantage which is easy to implement and computation time is faster than the genetic algorithm. Addition to PSO capabilities, PSO-NN composes a new hybrid method. Genuine and skilled forgeries are applied throughout the study to perform a consistency between the studies referred and performed here in terms of verification accuracies.

Table 2.1 Survey on Studies using Neural Networks(NN)

Method	Authors	Used Model	Image Resolution	Extraction	Forgery Type	Results
Neural Networks(NNs)	H. Baltzakısa, N. Papamarkos	2 stage NN using euclidean distance	Unknown	Global and grid inf.	Random& unskilled	%97 acceptance % 90 true rejection
	V. K. Madasu, M. Hammandlu	TS fuzzy NN	200 dpi 120x 60 pixel	Angles and equal horizontal density	Unskilled, skilled	% 91 acceptance rate
	M.Hafizuddin M.Yusof and Vamsi K. Madasu'	TS fuzzy NN	200 dpi 120x 60 pixel	Angles and equal horizontal density	Unskilled, Skilled	% 91 acceptance rate
	M, Dehghan, K. Faez, M. Fathi,	MLP NN with Back propagation	300 dpi 8 bit grey level	Shape descriptor,skeleton, envelopes and high pressure	Skilled& unskilled	%96 unskilled % 90 skilled
	Ng. G. See and O. L. Seng	NN with Back propagation	Unknown	Full signature, global	Unskilled	Unknown
	Jean-pierr drouhard, robert sabourin and mario godbout	NN with Back propagation	Unknown	Global shape vector, probability Dens. Func.	Random& unskilled	%94 rejection
	R. W. Zhou, C. Quek	Pseudo-Outer product Fuzzy NN	Unknown	Global baseline, slant features, pressure	Unskilled	%24.89 error rate
	C. S. Edson J. R. Justıno, F. Bortolozzi and R. Sabourin	NN classifier	Unknown	Graphometric features	Random	% 8.02 total error
	N. A. Murshed, F. Bortolozzi and R. Sabourin	Fuzzy artmap NN	512x128 pixels grey level	Identity grid seg.	Genuine signatures	%7.27- 28.18 FRR % 11.00- 0.25 FAR
	R. Sabourin, G. Genest, and F. J. Prêteux	NN and a threshold classifier	512x128 pixel	Granulometric size distribution for local shape descriptor	Random	%1.0 error rate
	I.Pottier, G. Burel,	Multi layer perceptron NN Identification	Unknown	Global features	Unknown	% 97.22 matching
	K.Huang, H.Yan,	NN	100 dpi 8 bit grey scale	Core & high pressure region feature and border	Random&unskilled	%90 average correct

Table 2.2 Survey on Studies using Hidden Markov Models (HMM)

	Authors	Used Model	Image Resolution	Extraction	Forgery Type	Results
Hidden Markov Models(HMMs)	E.-M. Nel, J. A. Du Preez, B.M. Herbst	HMM	Unknown	Pen trajectory	Unknown	%89.3 thinning %91.5 skeletonization accuracy
	E. J.R. Justino, F. Bortolozzi, R. Sabourin	SVM & HMM	Unknown	Grid segmentation	Random& unskilled	%13 HMM %19 SVM Genuine rejection rate
	E. J.R. Justino, F. Bortolozzi, R. Sabourin	HMM	Unknown	Pixel density distribution and axial slant	Simple& skilled	%1.44 random %2.5 simple type 2 error %22.67 skilled
	C. S. Edson J. R. Justıno, F. Bortolozzi, R. Sabourin, and A. El-Yacoubi,	HMM	300 dpi 8 bit grey level	Horizontal and graphometric segmentation	Random	%2.5 type 1 %0.47 type 2 average error rate
	C. S. Edson J. R. Justıno, F. Bortolozzi, R. Sabourin	HMM	Unknown	Pixel distribution and grid segmentation	Random, simple& skilled	%1.44 random %2.5 simple type 2 %22.67 skilled
	M. A. Ferrer, J. B. Alonso, and C. M. Travieso	HMM, SVM	300 dpi 8 bit	Geometrical features	Random&Simple	%2.2 type 1 %3.3 type 2 random %14.1 type1 %12.6 type2 simple
	J. J. Igarza, I. Hernaez, I. Goirizelaia, K. Espinosa	HMM	600 dpi 8 bit grey level	Blobs perimeters	Random & unskilled	%27.57 EER

Table 2.3 Representation of the survey on other approaches

Authors	Used Model	Image Resolution	Extraction	Forgery Type	Results
Ian W. Mckeague	Bayesian Approach	Unknown	Baseline Curvature Time warping	Unknown	%12.4 reject rate %6.5 accept rate
Y. Mizukami m. Yoshimura	Extracted Displacement	Unknown	Euclidean distance	Random	%24.9 error rate
S. Ando and M. Nakajima	Genetic algorithm	200 dpi 290x100 pixel	Local features	Random&unskilled	%2.63 using local %15.63 complete average error
J.-B. Fasquel, M. Bruynooghe	Hybrid opto-electronic	300 dpi 8 bit	Stroke width	Random&unskilled	% 62.4 rejection rate
S. N. Srihari, C. Huang, H. Srinivasan, and V. Shah	General Overview of Forensic document processing				
J. K. Guo	Weighted distance	Unknown	Pixel path of each signature	Random&unskilled	Average 0.27 FRR 0.40 FAR
Madasu H., Mohd. H. Vamsi K.M.	Takagi Sugeno Fuzzy	200 dpi 120x60 pixels	Angle and distance features	Random& unskilled	%93.6 rejection rate %96.3 acceptance rate
M. Kalera, S. Srıharı and A. Xu	Bayesian Classifier	300 dpi 8 bit grey scale	Gradient and structural concavity	Skilled forgery	% 21.90 FAR and FRR
L. Wan, Zh.-C. Lın(2), R.-C Zhao	Multiple classifier	300 dpi 8 bit grey level	Global and local features	Simple and random	%62.53 total error
W. Hou, x. Ye, k. Wang	Survey of offline signature verification				
B. Fang	Statistical variations Matrix estimation technique	Unknown	Positional variations	Random and unskilled	%18.1 average error rate
V. B. Kulkarni,	Colour code algorithm	Unknown	Global, Exclusively preferences and auto correlation	Unknown	%80 accuracy
B. Fang and Y. Y. Tang	Tracking of feature and position				
H. Lv , W. Wang, C. Wang, Q. Zhuo	Support vector machine	300 dpi 8 bit grey scale	Moment, grey and stroke-width distr.	Unknown	%10 average error rate
S. N. Srihari, A. Xu and M. K. Kalera	Bayes classifier	300 dpi 8 bit grey scale	Gradient and structural concavity	Skilled	%21.90 FAR and FRR

CHAPTER 3

THE MATHEMATICAL BACKGROUND

3.1.Introduction

Swarm intelligence is firstly described in this chapter. Mathematical background of the Particle Swarm Optimization (PSO) and Neural Network (NN) are given successively. The proposed method, PSO-NN is then explained mathematically. The pseudo codes, flow chart and details of the algorithm are given briefly to understand its application.

3.2. Swarm Intelligence

Different algorithms have been recently revealed from the behaviours of swarm of biological organisms are employed in the literature to solve difficult and complex problems. These algorithms which are based on the problem-solving ability of social insects that live in colonies such as birds or fish, ants, bees, wasps, termites are referred as Swarm Intelligence (SI) algorithms. A SI meta-heuristic can be defined as algorithm which is inspired by the behaviour of social insect colonies and other animal societies. SI indicates a recent computational and behavioural metaphor for solving distributed problems that originally took inspiration from the biological examples provided by the social insects and by swarming, flocking, herding behaviours in vertebrates [41].

Swarm Intelligence as a term, is firstly used in 1988 by Gerardo Beni in the context of cellular robotic systems and describes any attempt to design algorithms or distributed problem-solving devices inspired from the collective behaviour of social insect colonies and other animal societies [42]. The objective of these models is to model the simple behaviours of individuals and the local interactions with the environment and neighbouring individuals, in order to obtain more complex behaviours that can be used to solve complex problems, mostly optimization problems [43]. Researchers in this field have proposed algorithms with the motivation from some models explaining the aspects of social insect behaviour.

Social insects have lived on Earth for millions of years, building nests and more complex dwellings, organizing production and procuring food. These insects interact with each other in some ways like bee dancing for food foraging, ants laying pheromone to the path, etc. This kind of communication systems between individual insects shows the connection between '*individual insect behaviour*' and '*collective intelligence'* of social insect colonies [42-44].

3.3. Particle Swarm Optimization (PSO) Algorithm

PSO is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling [45].

In the PSO algorithm, there is a swarm of particles moving in the n-dimensional problem space where each particle represents a potential solution. In simple terms, particles are "flown" through a multidimensional search space, where the position of each particle is adjusted according to its own experience and that of its neighbours [43].

The position of the particle is changed by adding a velocity v_i^k to the current positioning in equation (3.1).

$$x_i^{k+1} = x_i^k + v_i^k \tag{3.1}$$

It is the velocity vector that drives the optimization process, and reflects both the experimental knowledge of the particle and socially exchanged information from the particles neighbourhood.

There are two different PSO algorithms; '*global best PSO'* and '*local best PSO'* which are classified according to their size of neighbourhood. In this thesis, *global best PSO* algorithm is utilized.

Global best PSO is initialized with a group of random particles (solutions) and then searches for the optimum by updating generations. Each particle is updated by following two "*best*" values. The first one is the best solution - p_{best} - that a particle has achieved so far. The other one is the global best value - g_{best} - that is obtained by any particle in the population so far. After finding the two best values, the particle updates its velocity and positions with the following equations (3.2) and (3.3).

$$v_i^{k+1} = wv_i^k + c_1 r_1 (p_{best\,i} - x_i^k) + c_2 r_2 (g_{best} - x_i^k) \tag{3.2}$$

$$p_{best,i}^{k+1} = \begin{cases} p_{best,i}^{k} & if \;\; f(x_i^{k+1}) \geq f(p_{best,i}^{k}) \\ x_i^{k+1} & if \;\; f(x_i^{k+1}) < f(p_{best,i}^{k}) \end{cases}$$

Where;

v_i^k = the particle velocity,

x_i^k = position of the current particle (solution),

p_{best} = best solution value among the particle found in the current iteration

g_{best} = global best solution achieved so far

r_1 , r_2 = is a random number between (0, 1)

c_1 , c_2 = are learning factors – usually taken as $c_1 = c_2 = 2$ and

The fitness function is '*f*' that measures how close the corresponding solution is to be optimum. The inertia weight factor '*w'* in equation (3.2) can be calculated using equation (3.3) where *'iter'* is the iteration number in a particular instance and '$iter_{max}$' *is* the maximum number of iterations. Position change of a particle displacement is simply shown in Figure 3.1.

$$w = w_{max} - \frac{(w_{max} - w_{min})}{iter_{max}}.iter \quad where \quad 0.4 < w < 0.9 \tag{3.3}$$

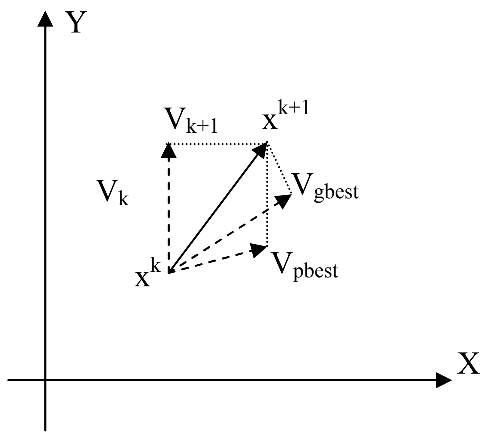


Figure 3. 1. Displacement change of a particle

The pseudo code of the global best PSO is given in Table 3.1.

Table 3.1 The pseudo code of PSO algorithm
Define PSO parameters (c_1, c_2, w, r_1, r_2)
Initialize Population
Calculate the fitness value of each particle
While (error criteria is not attained)
{Calculate p_{best} (local best) value of a particle
Calculate g_{best} (global best) value
Update velocity and position vector of each particle
Evaluate}
End Criteria (maximum iterations)

In implementing the PSO algorithm several parameters should be determined. These key parameters are the dimension of the problem, the number of particles, the acceleration coefficients, the inertia weight, the neighbourhood size, the number of iterations and the random values which scale the contribution of the cognitive and social components. The application of the algorithm is included in Chapter 6 in detail for offline SV use.

3.4. Neural Networks(NNs)

Neural networks have seen an explosion of interest over the last few years, and are being successfully applied across an extraordinary range of problem domains, in areas as diverse as finance, medicine, engineering, geology and physics. Indeed, anywhere that include the problems of prediction, classification or control, neural networks are being introduced [46]. NNs have proven to be a track record in predicting numeric or continuous outcomes [47]. Inspired from the problem solving ability of the human brain, this biologically inspired method of computing is thought to be the next major advancement in the computing industry.

NNs offer a mathematical model that attempts to mimic the human brain. The knowledge is represented as a layered set of interconnected processors those are named as neurones so as to indicate a relationship with the neurons of the brain. Each node has a weighted connection to several other nodes in adjacent layers. Individual nodes take the input received from the connected nodes and use the weights together with a simple function to compute the output values [47].

Learning is accomplished by modifying the network connection weights while a set of input instances is repeatedly passed through the network [47]. When the network is trained, the network can compute an output value to an unknown instance that is shown to the network.

There are three different learning methods which are known as *supervised, unsupervised and reinforcement learning*. If the correct output for the current input is required for learning, this type of learning is called as *'the supervised learning*'. A system is only presented with a set of exemplars as inputs in '*the unsupervised learning'*. The system is not given any external indication neither what the correct responses should be nor the generated responses are right or wrong. Finally, *'the reinforcement learning*' is somewhere between the supervised learning, in which the system is provided with the desired output, and the unsupervised learning, in which the system gets no feedback at all on how it is going. In the reinforcement learning, the system receives a feedback that tells the system whether its output response is right or wrong, however it does not give any information about which the right output should be.

Advantages can be classified as:

- Adaptive learning: An ability to learn how to do tasks based on the data given for training or initial experience.
- Self-Organization: NNs can create its own organization or representation of the information when it receives during learning time.
- Real Time Operation: NNs computations may be carried out in parallel, and special hardware devices are being designed and manufactured which can take advantage of this capability.
- Fault Tolerance via Redundant Information Coding: Partial destruction of a network leads to the corresponding degradation of performance. However, some network capabilities may be retained even with major network damage.

Main disadvantages of NNs are:

- Learning: The lack of the ability to explain NNs' behaviour, in other word understanding about what has been learnt.
- Convergence Rate: NN learning algorithms are not guaranteed to converge to an optimal solution. This is related with by manipulating various learning parameters.
- Test performance: NNs can easily be over trained to the point of working well on the training data but poorly on test data. This problem can be seen by consistently measuring the test set performance.

3.4.1 Simple Neuron

In the literature, definition of a simple neuron can be found as; an artificial neuron is a device with many inputs and one output. The neuron has two modes of operation; the training mode and the using mode. In the training mode, the neuron can be trained to fire (or not), for particular input patterns. In the using mode, when a taught input pattern is detected at the input, its associated output becomes the current output [47]. If the input pattern does not belong in the taught list of input patterns, the firing rule is used to determine whether to fire or not. The structure of a simple neuron is shown in Figure 3.2.

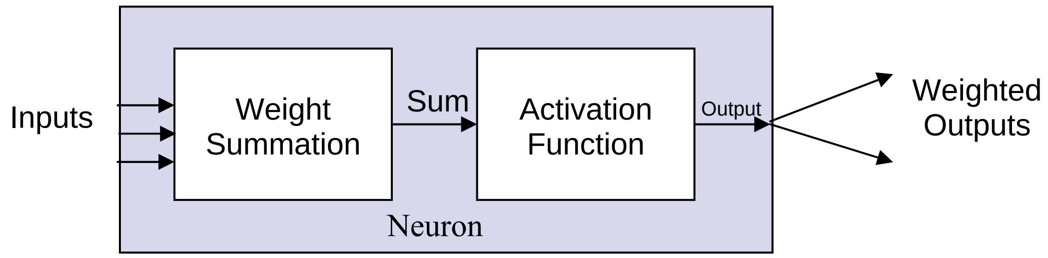


Figure 3.2. Structure of Basic Neuron

3.5 Applications on PSO

Up to date, PSO method has been applied to many different problems. One of the first applications of PSO was in the training of feed forward neural networks (FFNNs). The first studies in the training of FFNNs using PSO have shown that the PSO was an effective alternative to NN training [46]. There are a number of studies using PSO to train NNs for different applications in the literature. Some of these studies are summarized briefly as the following.

Zhang et al. [48] have studied on new evolutionary system for evolving artificial neural networks (NN), which is based on the PSO. From the results PSO-NN harmonizes the architecture and weights of NN. Alıcı et al. [49] have used the PSO algorithm for the prediction of the expected positioning errors of robot manipulators that cause due to their geometric parameters. Yin [50] has presented a new polygonal approximation approach based on the discrete PSO. Tang et al. [51] have studied a different variable neighbourhood model 'vbest' in PSO search method for NN learning, instead of 'gbest' and 'lbest'. Zhang et al. [52] have developed a hybrid PSO-BP algorithm for feed forward NN training. Different applications are illustrated with the test results. Yin [53] has used PSO based point pattern matching that determines an optimal transformation for given two point patterns. Da and Xiurun [54] have developed a PSO based NN with simulated annealing technique that is applied on triaxial compression tests for crack samples. Recently, in a mechanical application, Daş and Dülger [55] have designed a PSO algorithm for optimizing the parameters of the PD controller which is applied on position control of a four bar mechanism system.

3.6. The Proposed Method (PSO-NN)

With the motivation from successful applications in the literature a NN structure trained with the PSO algorithm is studied, designed and then applied to Signature Verification (SV) problem in this study.

For the solution of the SV problem, a NN structure that the input layer N has n nodes, hidden layer J with j nodes and output layer L with l nodes is designed and used. The inputs are determined as 'x_i' and the outputs are determined as 'd_l'.

The general representation of the neural network used in this study is shown in Figure 3.3.

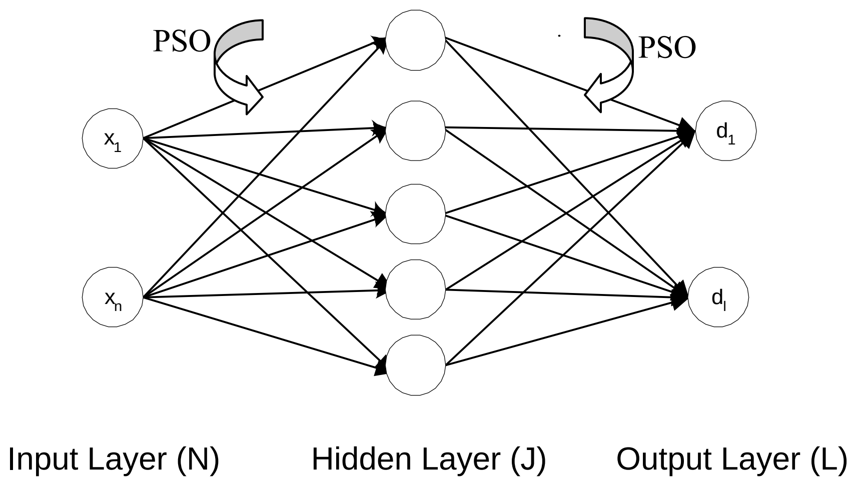


Figure 3.3. General representation of a NN

The proposed NN structure is trained with PSO which offers a simple and effective way as a search algorithm. The hidden and the output transfer functions are both assumed as sigmoidal function. The output of the hidden node is calculated as [56-58].

$$f(j) = 1/(1+\exp(-\lambda(\sum_{n=0}^{N} w_{nj}\cdot x_n - \theta_j))),\; j = 1,2,..,j \qquad (3.4)$$

Where w_{nj} is the weights between the n^{th} node of input layer and j^{th} node of hidden layer, θ_j is the threshold of the hidden layer, x_n is the n^{th} input and λ is the activation gain. The desired output d of the l^{th} output layer d_l is [57, 58] given as;

$$d_l = \sum w_{lj} \cdot f(j) - \theta_l \,, \; l = 1, 2, \ldots, l \tag{3.5}$$

Where w_{lj} is the weight from the j^{th} hidden node to the l^{th} output node, θ_l is the threshold of the output layer. The error E[n] is the sum of squares of the error over all output units. M is the set of trained example [57, 58].

$$E(n) = \frac{1}{2}\sum_{j=1}^{L}[d_{actual}(n) - d_{desired}(n)]^2 \tag{3.6}$$

Where; $\quad E_T = \sum_{n=1}^{m} E(n)$

d_{actual} = The actual output value taken from the system

$d_{desired}$ = The desired output value in each iteration

E_T = The total error

This error is accepted as the fitness function of a particle which is shown below.

$$Fitness(particle_i) = E_T = \frac{\sum (d_{actual} - d_{desired})^2}{2} \tag{3.7}$$

The weights between the n^{th} node of input layer and j^{th} node of hidden layer, W_c ($w_{00}, w_{01}, \ldots, w_{jn}$) and the j^{th} node of hidden and l^{th} node of the output layer, W_{hc} ($w_{00}, w_{01}, w_{02}, \ldots, w_{lj}$) are represented as a matrix. The obtained weight vector is accepted as the dimensions of a particle. The particle is defined as:

Particles(:,:,i) = [W_c, W_{hc}]

$$W_c = \begin{bmatrix} w_{00} & w_{01} & \cdots & w_{0j} \\ w_{10} & w_{11} & \cdots & w_{1j} \\ \vdots & \vdots & \cdots & \vdots \\ w_{n0} & w_{n1} & \cdots & w_{nj} \end{bmatrix}, \quad W_{hc} = \begin{bmatrix} w_{00} & w_{01} & \cdots & w_{0j} \\ w_{10} & w_{11} & \cdots & w_{1j} \end{bmatrix}$$

3.7 Implementation of PSO-NN to Signature

Implementation of the algorithm to signature verification is not an easy task. PSO-NN algorithm is adapted to signature application. One signature example does not describe the signature distribution of a writer. So a signature database, GPDS is taken throughout the study. Having performed, image processing and feature extraction processes, extracted data are divided into two parts (train and test data) which are then normalized. Starting point of the algorithm begins after normalization. Input values are the extracted features for each signature which are normalized between '0' and '1'. Output value is also changed between '0' and '1' for each signature. Near to the '1' represents the *genuine signature*, the value of '0' represents the *forged signature* for output values.

Number of dimensions, particles, hidden layers and constant values (learning rates, λ, $c_1$and c_2) are given to the system; they are found with trial and error. Detailed information of the implementation of the algorithm is given in Chapter 6. Pseudo-code of PSO-NN learning algorithm can be seen in Table 3.2. Flow chart and application steps of PSO-NN are given in Figure 3.4.

Table 3.2. Pseudo-code of the proposed algorithm(PSO-NN)

Step 1: Initialization of the network
Choose the number of nodes for the input, output and hidden layers

Step 2: Determine the Initial value of weights between 1.0 and -1.0
Choose a learning rate between 0 and 1.0

Step3: Learning step and calculation of the weight values
Define PSO parameters (c_1, c_2, w, r_1, r_2)
Initialize Population
Calculate fitness value of each particle
While (error criteria is not attained)
{Calculate p_{best} (local best) value of a particle
Calculate g_{best} (global best) value
Update velocity and position vector of each particle
Evaluate}
End Criteria (maximum iterations)

Step4: Test the accuracy of the network on a test database.

Step5: If the accuracy is less than the desired error rate,
then give new parameters to the network and start again.

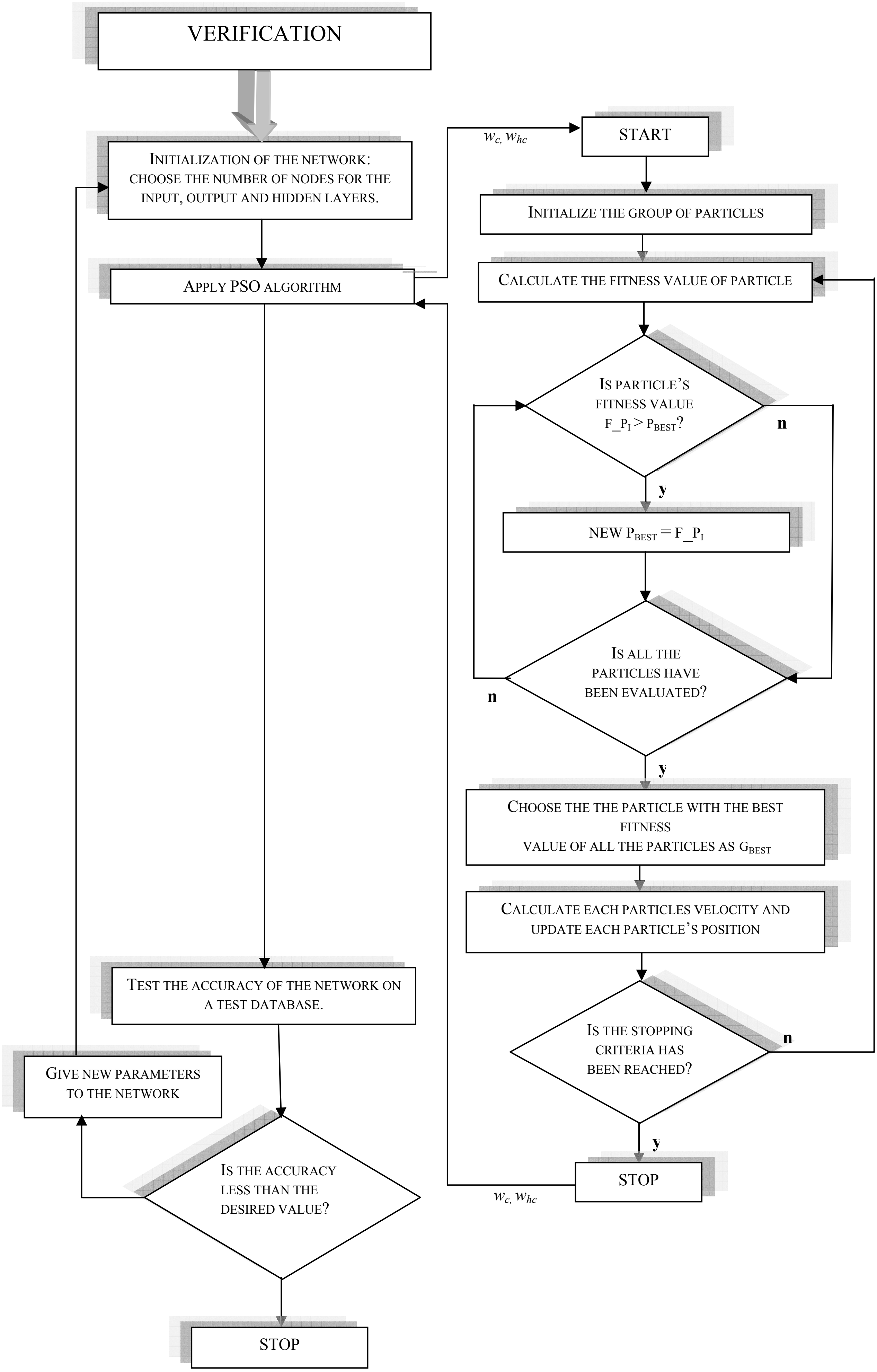


Figure 3.4 Flow Chart of the verification Process

CHAPTER 4

IMPQD SOFTWARE - OFF-LINE SIGNATURE VERIFICATION

4.1 Introduction

The basic definition of digital image is a sampled, quantized function of two dimensions that has been generated by optical means, sampled in an equally spaced rectangular grid pattern, and quantized in equal intervals of amplitude. Digitizing is the process of converting an image from its original form into digital form where numerical representations are adopted for each pixel value. Digital image processing is simply defined as the manipulation of images by computer [59]. Therefore, basic knowledge of the process has to be known while building up the software.

This chapter presents a functional overview of IMPQD and its detailed definitions of functional subtitles. It also covers techniques for classifying images for analysis. The image processing part of the menu is prepared with the basis of classical software menu. Addition to the classical software, controller action of the device, SV toolbox menu and verification parts are added to the software to enhance its ability for flexibility in use. So this chapter covers all of image processing features to make images ready for analysis and/or comparison.

4.2 IMPQD Software

Image Processing for Questioned Document (IMPQD) is developed by using C++Builder6.0. Menu options of the package are given in Figure 4.1. Addition to classical menu toolbox, image processing applications, signature verification toolbox, a camera control and a position control of X-Y table can be performed with IMPQD. This software is designed either examining the questioned document and/or signature verification. Open source image processing library has been used for creating the image and filter tool boxes. Camera controller is embedded into the original software which is connected to PC with IEEE 1394 protocol. Detailed information about camera acquisition will be given in Section 4.4.2. Parallel port control is used for X-Y table controller. Simple interface is also embedded in the IMPQD in which is explained in Section 4.4.1 as X-Y table controller toolbox. The execution of software can be used in any traditional Pentium 4 personal computer without any additional software. The verification process only requires C compiler.

4.2.1 Image Processing Menu toolbar

Basic and advanced image processing algorithms have been adapted on IMPQD software in this study. IMPQD supports the mostly used data file formats which are *.JPEG(Joint photographic experts group), *.PNG(Portable network graphics) *.TIFF(Tagged image file format), *.GIF(Graphical interchange format), *.BMP(Bit-mapped format).

When a user sets up the software, the general window is seen in Figure 4.1, which illustrates the menu options of the IMPQD software. Image processing toolbox menu will be explained as the following. Actions on menu tool bar are explained either with an signature or a logo.

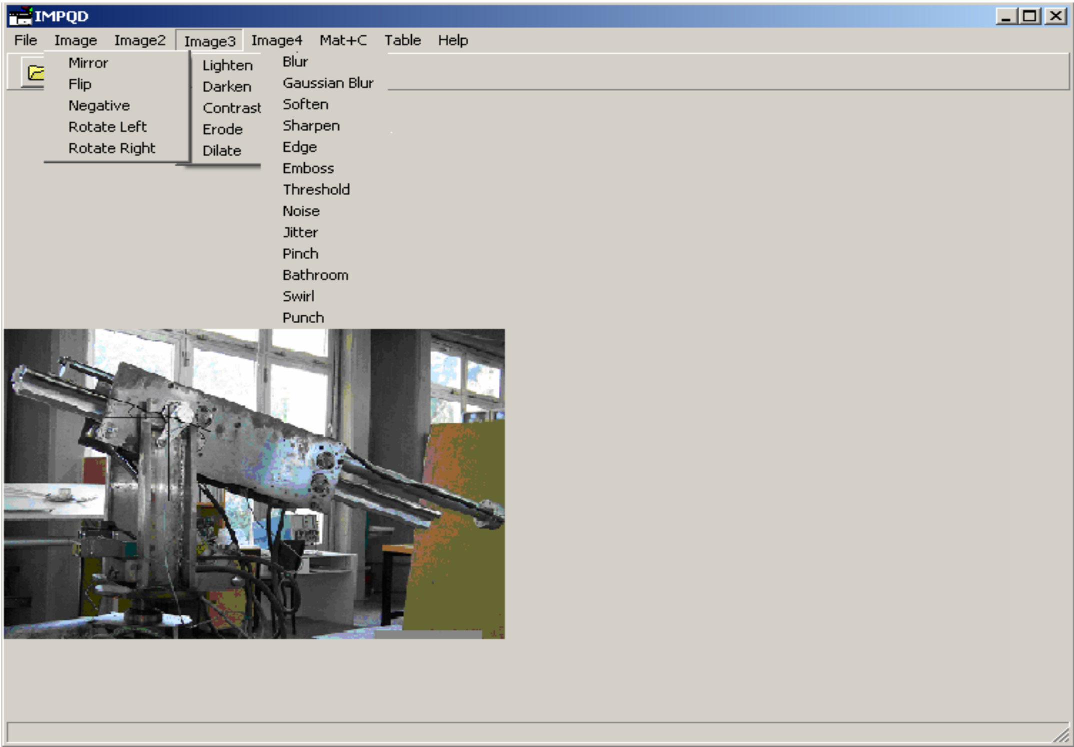


Figure 4.1 IMPQD with Image Processing Units(8 Dialog boxes)

File	New, Open, Save, Save As, Print, Send, Exit
Image	Mirror, Flip, Negative, Rotate Left, Rotate Right, Skew, Resample
Image 2	Gray Scale, Negative, Dither
Image 3	Lighten, Darken, Contrast, Erode, Dilate
Image 4	Blur, Gaussian, Median, Soften, Sharpen, Edge, Emboss, Threshold, Noise, Jitter, Pinch, Bathroom, Swirl, Punch
Mat + C	Neural Network and Signature Verification Toolbox
Table Control	X-Y table and Camera controller
Help	About

4.2.2 IMAGE (Mirror, Flip, Rotate, Resample, Skew)

Geometric operations are image-to-image operators that perform geometric modifications in image. Geometrical algorithms generally change the shape of the images. These changes are done through by changing the number of pixels, location of pixels, or mutual position of pixels base or some geometrical transform. The following geometrical transformations are often used for analysing images: Mirror, rotation, resampling, flip, skew options of the toolbox. They are shown in Figure 4.2.

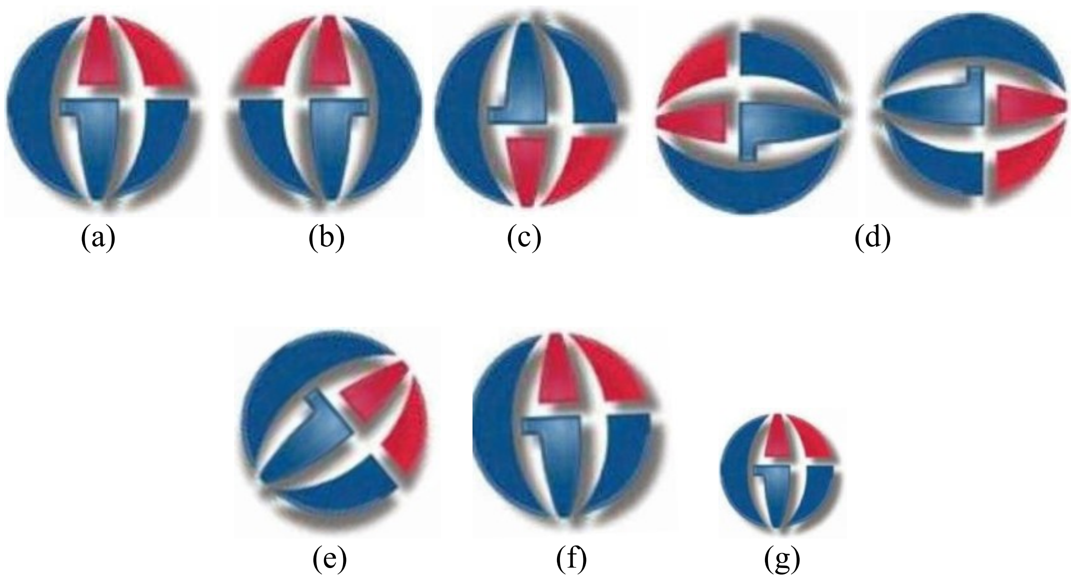


Figure 4.2 The images show
(a) Original, (b) Mirror, (c) Flip, (d) Rotate Left and Right,
(e) Rotate with angle (f) Skew, (g) Resample

By clicking 'Image' the geometric operations dialog box open. It provides a menu to select your operation.

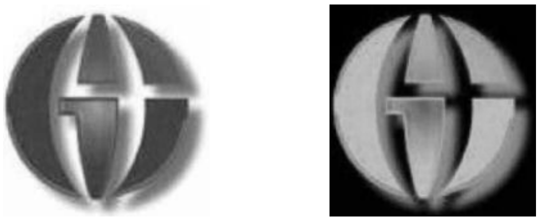
4.2.3 IMAGE 2

When the user clicks on 'IMAGE2', gray scale, negative and dither options are enabled to choose application.

4.2.3.1 Gray Scale and Negative

A gray scale (or gray level) image is simply one in which the only colors are shades of gray. The reason for differentiating such images from any other sort of color image is that less information needs to be provided for each pixel. In fact, a gray colour is one in which the red, green and blue components all have equal intensity in RGB space, and so it is only necessary to specify a single intensity value for each pixel, as opposed to the three intensities needed to specify each pixel in a full colour image[59]. Often, the gray scale intensity is stored as an 8-bit integer giving 256 possible different shades of gray from black to white. Gray scale images are entirely sufficient for some applications. Therefore there is no need to use more complicated and harder-to-process colour images.

Negative of an image with gray scale is obtained by using the negative transformation. Reversing the intensity levels of an image in this manner produces the equivalent of a photographic negative. This process is generally used for enhancing white or gray detail embedded in dark regions of an image [60]. Gray scale and negative applications are illustrated in Figure 4.3(a) and (b).



(a) (b)

Figure 4.3 (a)Gray Scale and (b) Negative conversion options and the resulting images

4.2.3.2 Dither

Dithering is an image display technique that is useful for overcoming limited display resources. The word *dither* refers to a random or semi-random perturbation of the pixel values. Example application can be seen in Figure 4.4.

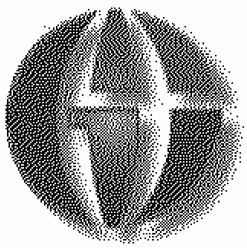


Figure 4.4 Dither option and the resulting image

4.2.4 IMAGE 3

When the user clicks on ‘IMAGE3’, basic operations; Lighten, Darken, Contrast, Erode and Dilate are included in the down menu.

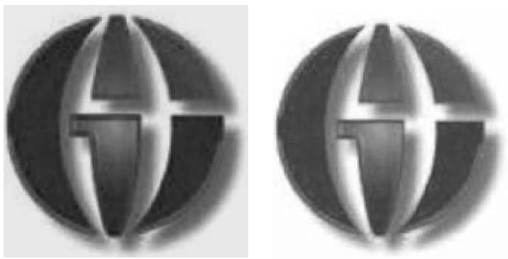
4.2.4.1 Lighten, Darken and Contrast

The IMAGE 3 preferences enable the user to choose lighten, darken and contrast actions. The brightness and the contrast of the image are changed. Parameters of the brightness can be from -255 to 255, if brightness is negative, the image becomes dark. Parameters of contrast can be taken a value from -100 to 100, the neutral value is 0. Simple application of the tools can be seen in Figure 4.5.

Figure 4.5. Lighten, Darken and Contrast options respectively and the resulting images

4.2.4.2 Erode and Dilate

The other basic operations in mathematical morphology are erosion and dilation. Both of these operators take two pieces of data as input: an image to be eroded or dilated, and a structuring element (also known as a *kernel*). Two pieces of input data are treated as representing sets of coordinates in a way that is slightly different for binary and grayscale images. Dilate enhances the light areas of the image[60].Erode enhance the dark areas of the image. Example application is given in Figure 4.6.



(a) (b)

Figure 4.6. Erode and Dilate options respectively and the resulting images

4.2.5 IMAGE 4

The actions on filter are included in IMAGE4 preferences.

4.2.5.1 Available Filters

Filters are generally used to eliminate the high and low frequencies; as smoothing the image, as enhancing or detecting edges in the image. An image can be filtered either in the frequency or in the spatial domain. Some of the filtering examples can be given as median, Laplace, Gaussian filters are given in the following part. They are included in the following as in IMAGE 4 preferences.

a.Threshold

Thresholding obtains an easy and convenient way to separate out the regions of the image on the basis of the different intensities or colours in the foreground and the background regions of an image. That is also useful to observe which areas of an image consist of pixels whose values lie within a defined scale. Figure 4.7 shows the application example of threshold.

Figure 4.7. Threshold option and the resulting image

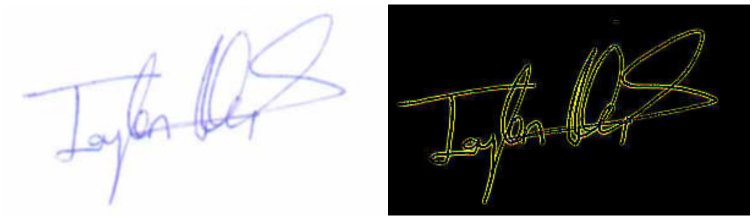
b. Median Filter

The median filter is one for smoothing and reducing or eliminating certain types of noise. It works by calculating the median on its neighbouring pixels and then setting itself to that value. The median filter can be used more than once to remove outliers that are hard to remove by just one pass. The filter is applied on each pixel in the image, by storing the intensity values, sorting them, and selecting the median, which in the form of 3x3 matrix. Figure 4.8 illustrates an application of median filter on the signature.

Figure 4.8 Application of Median Filter

c. Laplace Transform

The Laplace transform is a 2D isotropic measure of the 2nd spatial derivative of an image. Regions of the Laplacian of an image consist of sharp intensity change; therefore it is generally used for edge detection [60]. The Laplacian is often applied to an image that has been smoothed with a Gaussian filter to reduce its sensitivity to noise. Simple application of Laplace is shown in Figure 4.9.



a.Gaussian filtered b. Laplace transformed

Figure 4.9 An application of the filtered image

d Blur

Blurring is a part of image restoration. The blur filters smooth transitions by averaging the pixels next to the hard edges of defined lines and shaded areas in an image. Blurring application can be seen in Figure 4.10.

Figure 4.10 Blur option and the resulting image

e. Sharpening and Edge Detection

Edge detection provides an automatic way of finding boundaries of one or more objects in an image. It allows to single out a particular subject of interest from an image containing many objects. Many different methods can be used for edge detection. This method is applicable for determining constant displacement from typical points of signatures used for comparing original one from forgery. Simple procedure can be given as the following.

An image will be processed in the program consisting of pixels. Each pixel is assigned as a number. In the gray level, white may be given as the value “1”, and black as the value “0”. An image can therefore be represented as a mathematical function that can be manipulated using mathematical operations (addition, subtraction, differentiation, etc.) For each pixel in the image, the colour intensity of the pixel can be measured and subtracted from the colour intensity of nearby pixels. If the pixel lies in a region with roughly uniform colour intensity then the intensity difference will be small. If the pixel lies in a region with sharp changes in intensity then the intensity difference will be large [60] showing an edge. Figure 4.11 shows an application of edge detection and sharpening.

(a) Sharpening (b) Edge detection

Figure 4.11. Sharpening and Edge detection actions and the resulting image

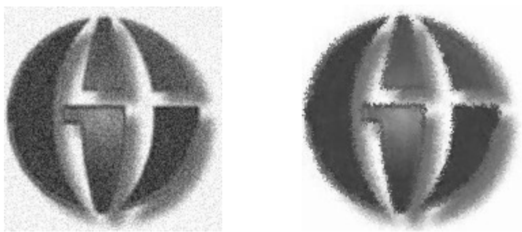
f. Emboss

Emboss is the process of creating a three-dimensional image or design in paper and other ductile materials. It is typically accomplished with a combination of heat and pressure on the paper. This is achieved by using a metal die (female) usually made of brass and a counter die (male) that fit together and actually squeeze the fibers of the substrate[1]. An image is embossed which the color at a given location of the filtered image corresponds to rate of change of color at that location in the original image. Embossing function can be seen in Figure 4.12.

Figure 4.12 Emboss action and the resulting image

g. Noise and Jitter

Noise adds an uniform noise to the image. Jitter adds a random offset to each pixel in the image. Example applications are given in Figure 4.13.

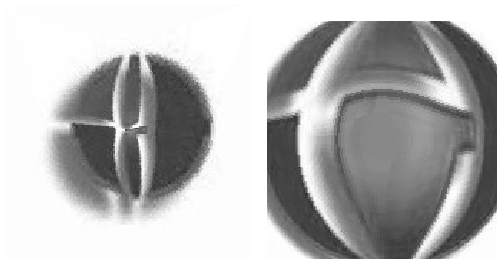


(a) (b)

Figure 4.13 Noise and Jitter options respectively and the resulting images

h. Pinch and Punch

The operation pinch is rotation of the image through inside around the centre. The punch is the opposite direction of the pinch in which the rotation is through outside around the centre. The pinch and punch operations are illustrated in Figure 4.14.

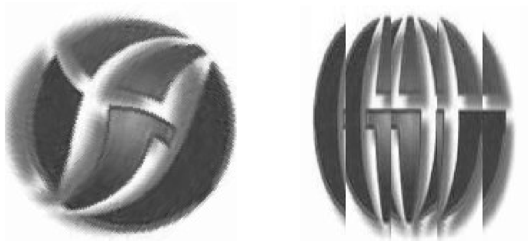


(a) (b)

Figure 4.14 Pinch and Punch options and the resulting images

i. Swirl and Bathroom

Swirling is the rotation of the image around the fixed centre. Bathroom option creates image like in the liquid. It looks like the broken of the picture. The swirl and bathroom options can be seen clearly in Figure 4.15.



(a) (b)

Figure 4.15 Swirl and Bathroom options respectively and the resulting images

4.3. Mat+C

Signature verification toolbox and verification options can be seen in this menu option. C++ program compiler is also added for verification process in the menu.

4.3.1 Signature Verification Toolbox

More information on signature verification is given in the Chapter 6. Toolbox working principle and related tools will be introduced in this section. A signature verification toolbox example and tools is seen in Figure 4.16. The pre-processing of the toolbox will be explained in Chapter 6. Region of interest, resampling, normalization, erode and dilation and thinning operations are applied on the signature respectively.

- A **Row and Column** displays the number of division about the divided images.
- A **Thinning** is defined value of thinning operation.
- A **Select Threshold** is used threshold value on the images.
- A **Processing** preprocess the given signatures defined in signature verification section. After preprocessing, Dividing application is occured on the images for given row and column number for each image.
- A **Calculate** makes the calculation of feature extraction
- A **Multi** is used to prepare all selected signatures for saving. First of all, image is resampled to given data. Then, pre-processing and calculate sections are processed respectively. Finally, the user must save only data file taken from the all signatures.
- A **Save** includes values of features and creates the .dat file.
- An **Intelligent** makes the all process given above with single image selection. Row and column divisions are divided vertically in equal size cells.

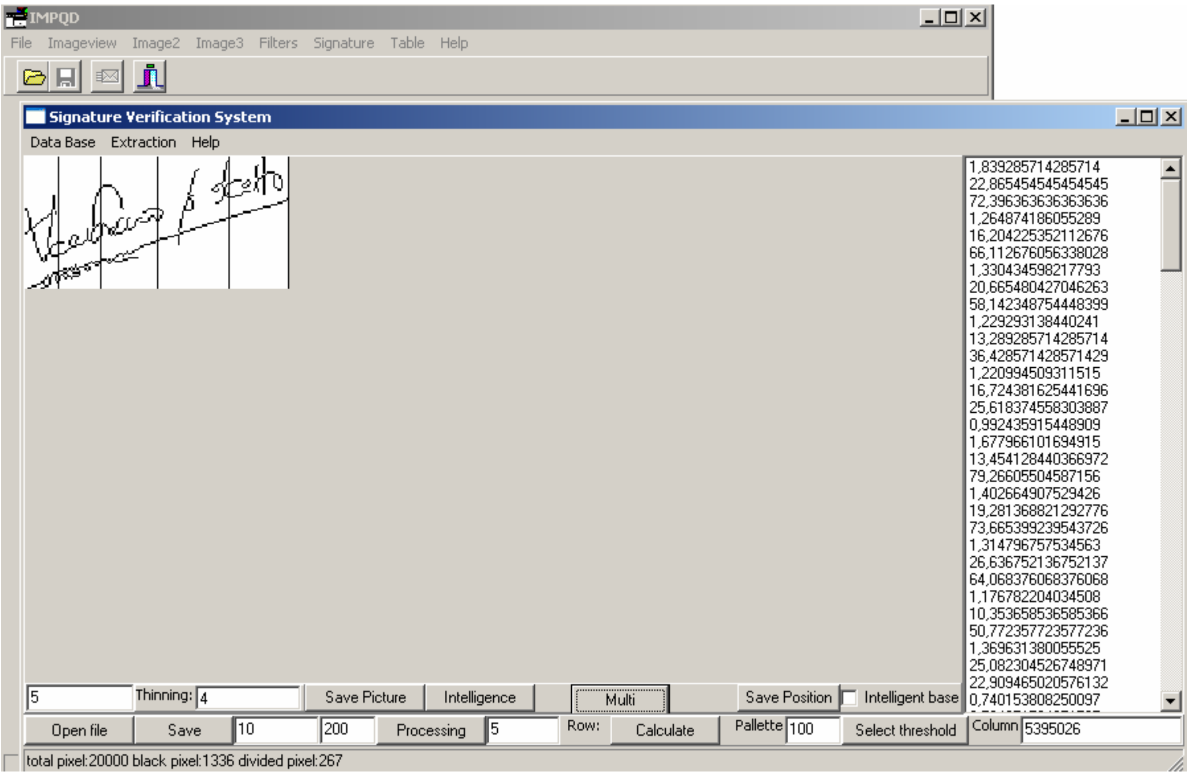


Figure 4.16 IMPQD with Signature Verification Toolbox

4.3.2 Verification

Verification tool is not an interface, it needs the C++ program and the proposed method to get it compiled. The person who uses the program must be initializing the input and output data files from the program. Transform file is firstly used to normalize all inputs and outputs. The normalized signature inputs and outputs are divided into two parts as train and test. After normalization, compiling must be performed for the training section. Then the program must be run for the testing part of the signatures. Parameters of the proposed method PSO-NN are initially adjusted. They are the number of particles, the number of dimensions, the number of parameters and the constants for PSO and NN for training process. After training, weights of the network are obtained in data file that is used in test part of the algorithm. Finally, test results can be seen in an output data file. This is explained in Chapter 6, in the section named ‘Verification with PSO-NN’.

4.4 Table Control

4.4.1 X-Y Table Control

In this study, X-Y table is considered for the motion control of light sources in the system. Table is actuated independently by stepper motors, and controlled by parallel port. Interface of the table is performed as the motion up and down, left and right with full/half speed. In additional to above, the coordinates can be uploaded on the table. Home position can also be changed for the direction chosen. Technical information of the table will be included in Chapter 5. X-Y table motion interface can be see on the screen as in Figure 4.17.

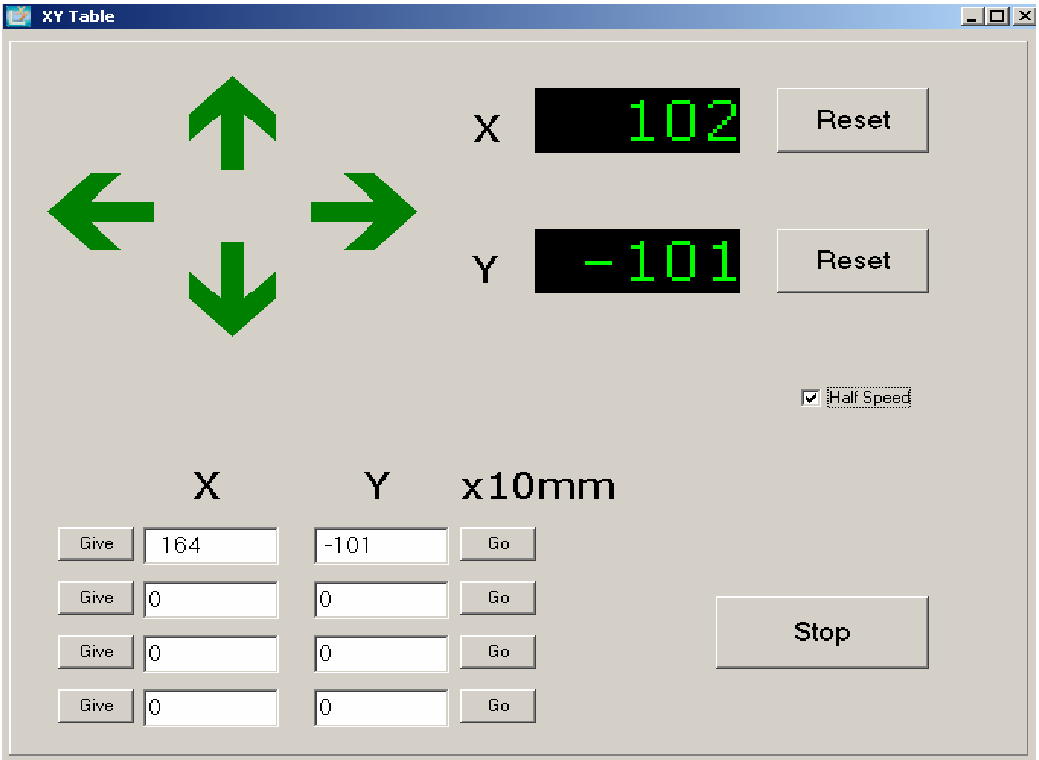


Figure 4.17 IMPQD with X-Y table menu tool

4.4.2 Camera Control

Basler A102fc CCD camera and its software is used for the study. Specifications of the camera are given in Chapter 5. BCAM Camera Viewer program allows changing of the settings easily on IEEE 1394 camera. So the images can be captured in either single or continuous mode. When the viewer program is started, a start-up window, similar to the one shown in Figure 4.18 is seen.

The elements of the start-up window include the followings.

- A **File Menu** is operated in standard Windows fashion and allows to access all of the features of the program.
- A **Tool Bar** contains shortcut tools used to control the program.
- A **Camera Features Bar** includes sliders for adjusting the various camera parameters, which are brightness, shutter, gain, file size, and colour parameters
- A **Bus Viewer** displays all cameras currently connected to the 1394 bus.
- An **Image Viewing Area** where the captured images will appear.
- A **Status Bar** displays information about the captured images.

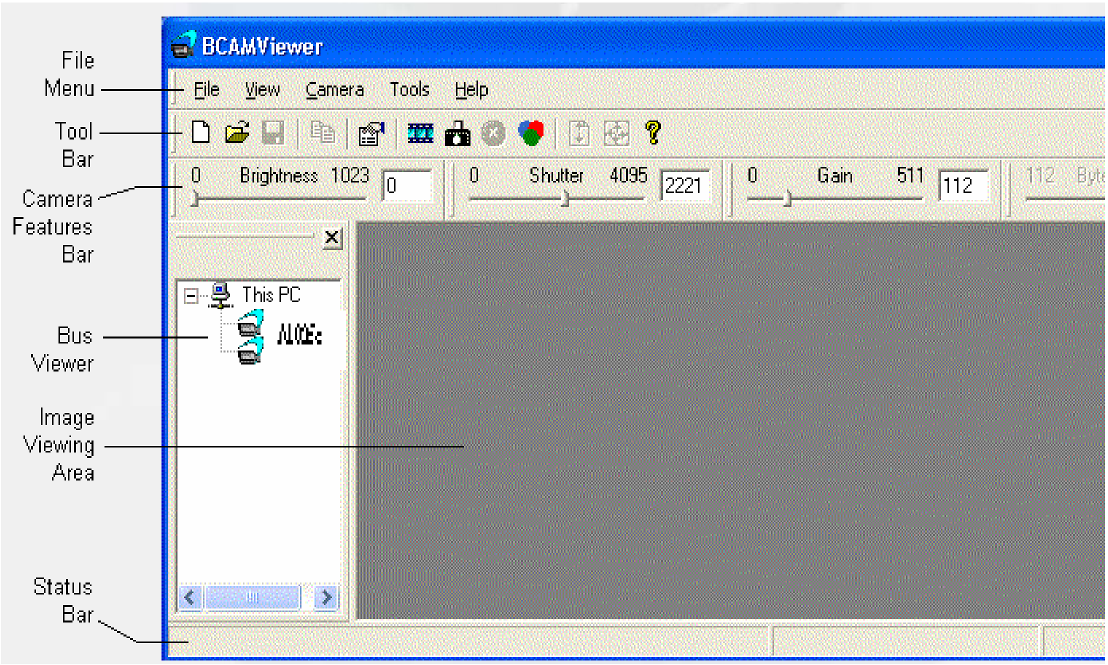


Figure 4.18 IMPQD with Basler camera menu toolbar

CHAPTER 5

DESIGN AND IMPLEMENTATION OF QUESTIONED DOCUMENT DEVICE

5.1 Introduction

Questioned documents have been suspected of being deceitful or whose source has not been known. There may be a variety of reasons for questioning a document. A questioned document might have been prepared with any of the numerous materials available. The examiners of questioned documents can answer the needs of the courts for assistance in interpreting evidence relating to the preparation and subsequent treatment of documents. The most important point in document examination is not to destroy the original condition of the document [61].

This chapter presents design and implementation of a questioned document device. It is supported by Gaziantep University Research Project Unit for duration of 2 years. Mechanical properties of device, illumination details, and colour isolation techniques are used to enhance objects in an image of questioned document to show details better. Application examples of some material are included at the end of chapter.

5.2 Questioned Documents

The most important tool of a document examiner is his/ her vision. Specially designed lenses, modern opto electronics and digital technologies can help to solve the questions in documents under inspection. The camera and magnifying lenses are the two most useful tools. Special lighting features and lens systems also facilitate a variety of examinations performed; like control of illumination, the quality of light, control of its direction and angle of illumination. Most of the traditional methods of forensic analysis are based on "*eyeballing*" of an image/specimen visualized at 256 levels of grayscale. An examiner eye can distinguish 20-30 individual grayscale levels on average. The actual number depends upon individual eye sensitivity as well as the physical condition of observation; such as, angle of view, object shape, size and boundaries. The human eye and brain can distinguish at least several tens of thousands of different individual colours. The human vision acts in a way to enhance our ability to detect colour differences rather than with colour itself [62,63].

5.2.1 Previous Studies on Questioned Documents

A brief literature survey is performed in the field of luminescence and handwritten signature examination types for questioned documents.

Hardcastle et al. [64] have been introduced a method to detect enhanced luminescence of ink components thereby differentiating many kinds of ink. The inks under investigation has been illuminated with blue/green light and any infrared (IR) luminescence, and then recorded photographically on an infra red sensitive film via a filter, which had been only permitted to the passage of infrared light.

Sensi et al. [65] have studied on infrared luminescence as a method for differentiating inks. Infrared luminescence had been found to be the most useful and effective for the non-destructive examination of documents. Luminescence was not major method to examine the handwritten documents and signature. They have been classified inks into three main classes; inks containing components that luminescence, inks that contain no luminescent components and inks containing some components that luminesced and the rest did not.

Sinor et al. [66] have used lasers and optical spectroscopy for questioned document examination. In ink examination, inks could have been distinguished visually via laser-induced fluorescence. IR luminescence photographs of samples tracing had been undertaken using an Ar-laser excitation.

Cantu et al. [67] have worked on spectral recording of luminescence observation on inks separated by thin layer chromatography (TLC), which has been defined as one of the simplest and most widely used chromatographic techniques. In TLC the stationary phase was a layer of powdered materials adhering to a smooth support such as a glass plate, aluminium or plastic sheet.

Moshe et al. [68] have studied to reanalyze the data collected in order to compare results of hand-printed (HP) and non-hand-printed (NHP) documents statistically. They have been examined by forensic document examiners (FDE) and laypersons. The data provided by FDE and the data taken from lay persons have been found to be significantly statistically different.

5.3 Illumination

The use of different light sources with illumination techniques is a standard in any non-destructive questioned document examination. If the light strikes the surfaces of the document at a very low angle, a grazing illumination is produced. Under oblique lighting, a different amount of light is reflected from shadowed and non-shadowed areas on the document surface, providing greater contrast. The resulting enhancement is helpful for the detection of surface roughness due to mechanical erasure, characteristics of imprinting, embossed seal impressions or indented writings. Information from indented impressions can provide an important link between the document and a criminal, and assist in identifying the suspect. Indented impressions can not be visible when examined by normal reflected light [62]. Therefore, the use of an appropriate lighting method is important. Table 5.1 shows the classifications of electromagnetic waves.

Table 5.1 Classification of Electromagnetic Waves

Frequency(Hz)	Wave Length (m)	Sources
10^{16}-	10^{-8}-10^{-12}	γ-ray
10^{15}-	10^{-10}-10^{-12}	X-ray
10^{15}-10^{14}	10^{-6}-10^{-8}	Ultraviolet
10^{14}	10^{-5}	Day light
10^{14}-10^{10}	10^{-2}-10^{-5}	Infrared
10^{12}-10^{8}	10^{0}-10^{2}	Microwaves
10^{8}-10^{4}	10^{4}-10^{2}	Radio Waves

Infrared light source is used for ink and paper examinations to reveal differences although the entire document appears be done in the same ink. Ultraviolet light source is used to reveal chemical alterations and erasures. Laser light source is also used for examining documents especially for characterizing inks on documents. The word laser is derived from "*light amplification by stimulated emission of radiation*". The main physical differences between laser light and light produced by other light sources is that the former is monochromatic; single wavelength, coherent and very intense. The coherence of light is not, at present, employed for the detection of fingerprints and questioned documents. The high intensity is necessary when the excited compound exhibits a low quantum yield. Monochromatic light supplied by a laser is only an advantage if its wavelength corresponds to/or approximates, the maximum absorption of the compound under investigation. Each type of laser only operates at a limited number of wavelengths. Here spectral imaging technology and advanced processing are both applied to detect very small differences between inks and papers [63].

5.4 Development of Questioned Document Device

This device is developed at Gaziantep University, Mechanical Eng. Dept., Dynamic Systems Laboratory. It is designed to investigate A4 size documents. Device includes 5 parts; the frame, X-Y table, a camera, a platform for carrying different light sources and a computer. The X-Y translation axes provide complete flexibility on fine positioning of a document and also for light sources. The platform is driven by stepper motors and controlled with parallel port protocol. 1392 x 1040 pixels resolution digital CCD colour camera (Baslera102fc), which is 8-12 bits/pixel, synchronization by IEEE 1394 protocol, is integrated to perform image capturing. It is to be used with an interface & software called IMPQD. Thus this system can be used for SV purpose separately, or document examination or both at the same time depending on requirement.

Illumination is studied by ultraviolet and infrared LEDs and lamps especially for detection of invisible characters hidden in the document. Firstly, LEDs are used for UV, IR and daylight illuminations. LEDs are mounted on the X-Y table which changes the direction of light without changing the document. Normal UV and IR light sources are fixed to the upper surface of the device. Infrared light source is used for ink and paper examinations to reveal differences although the entire document appears be done in the same ink. UV light source is then used to reveal chemical alterations and erasures. Studies on illumination with different light sources and the effect of motion on the light sources are then performed.

5.4.1 Light Emitting Diode (LED) and Their Applications

The definition of the Light Emitting diode (LED) is a semiconductor diode that emits incoherent narrow-spectrum light when electrically biased in the forward direction of the p-n junction, as in the common LED circuit [66 69]. A **p-n junction** is formed by combining P-type and N-type semiconductors together in very close contact. Creating a semiconductor from two separate pieces of material introduces a grain boundary between them which would severely inhibit its utility by scattering the electrons and holes [1].

The colour of the emitted light depends on the composition and condition of the semi conducting material used, and can be infrared, visible, or ultraviolet. LEDs are produced in an array of shapes and sizes. The 5 mm cylindrical package (red, fifth one from the left to the right in Figure 5.1) is the most common, estimated at 80% of world production. The colour of the plastic lens is often the same as the actual colour of light emitted, but not always. For instance, purple plastic is often used for infrared

LEDs, and most blue devices have clear housings. Types of LEDs can be seen in Figure 5.1

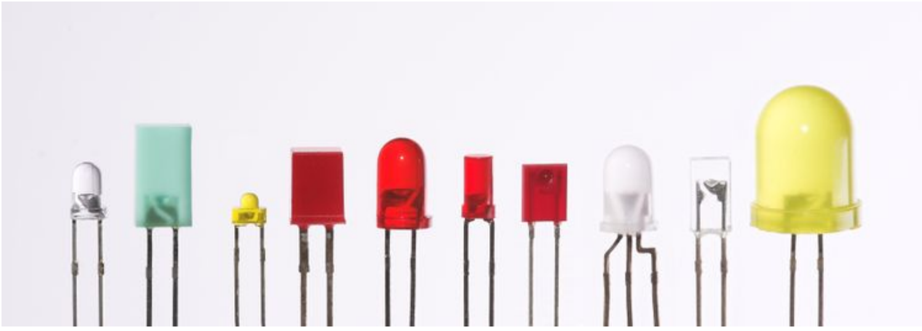


Figure 5.1 Types of LEDs

Machine vision systems often require bright and homogeneous illumination, so features of interest are easier to process. LEDs are often used to this purpose, and this field of application is likely to remain one of the major application areas until price drops low enough to make signalling and illumination applications more widespread. LEDs constitute nearly an ideal light source for machine vision systems for several main reasons. They can be summarized as the following.

- LEDs come in several different colours and wavelengths, easily allowing to use the best colour for each application, where different colour may provide better visibility of features of interest. Having a precisely known spectrum allows tightly matched filters to be used to separate informative bandwidth or to reduce disturbing effect of ambient light.
- LEDs usually operate at comparatively low working temperatures, simplifying heat management and dissipation, therefore allowing plastic lenses, filters and diffusers to be used. Waterproof units can also easily be designed, allowing for use in harsh or wet environments (food, beverage, oil industries).
- LED sources can be shaped in several main configurations (spot lights for reflective illumination; ring lights for coaxial illumination; back lights for contour illumination; linear assemblies; flat, large format panels; dome sources for diffused, omni directional illumination).
- Very compact designs are possible, allowing for small LED illuminators to be integrated within cameras and vision sensors [69].

5.4.2 Filters (Bandpass filters)

Optical bandpass filters are designed to transmit a specific waveband. They are composed of many thin layers of dielectric materials, which have differing refractive indices to produce constructive and destructive interference in the transmitted light. In this way optical bandpass filters can be designed to transmit a specific waveband only [70].

The range limitations are usually dependant upon the interference of filters, lenses, and the composition of the thin-film filter material. Optical bandpass filters designed to transmit near infrared wavelengths are tuned to in 750 nm to 2500 nm wavelength range; visible, for use in 380 nm to 750 nm wavelength range; and ultra-violet, for use in 4 nm to 380 nm wavelength range [71]. Thorlabs bandpass filters are between 370nm and 940nm with 10nm incremental are used on the device. An example of a filter wheel and sample filters are shown in Figure 5.2.

Figure 5.2 Filter wheel and sample for filters

5.5 Design of Device

Design parameters and the parts of the device are presented in this section. The device consists of five main parts;

- The frame (Aluminium Sigma Profile)
- The X-Y table (Operated by two stepper motors)
- A camera (Basler A102fc CCD) & Filter Wheel (Thorlabs)
- Light sources (IR, UV, Daylight)

The main body of the device is constructed with 30x30mm Aluminium sigma profile. Assemble of the device is completed. A simple sketch of the designed device and parts are given in Figures 5.3 and 5.4 respectively. Figure 5.5 illustrates the detailed structure of device.

Design and assembly of this device is fully completed. The working area of the table is 300x300mm. IR 850nm and UV 380nm LEDs which are powered by 9 VDC and 2x8W UV lamps are mounted on the table. Daylight LEDs are connected with flexible joint which introduces the flexibility for moving different angle to change illumination. Basler camera and Thorlabs filter wheel are located on the device to acquire A4 size document. Addition to the LEDs 18W blacklight UV and 250W 220 VAC IR lamps are fixed on the device. Conventional devices are generally lightened from the top surface and used only lamps. The experts move the documents with hands that condition is not suitable for health conditions (especially for eyes), because of the UV and IR light sources. Direct touching or continuous visual observation of these light sources is dangerous for human health. Therefore, the device is designed to operate in open & closed form which means that the user can open the box and put the document, analysing switch on and then switch off light sources. The use he/she then takes the document back. It certainly provides full flexibility. Assembly photographs of the device are shown in Figure 5.6.

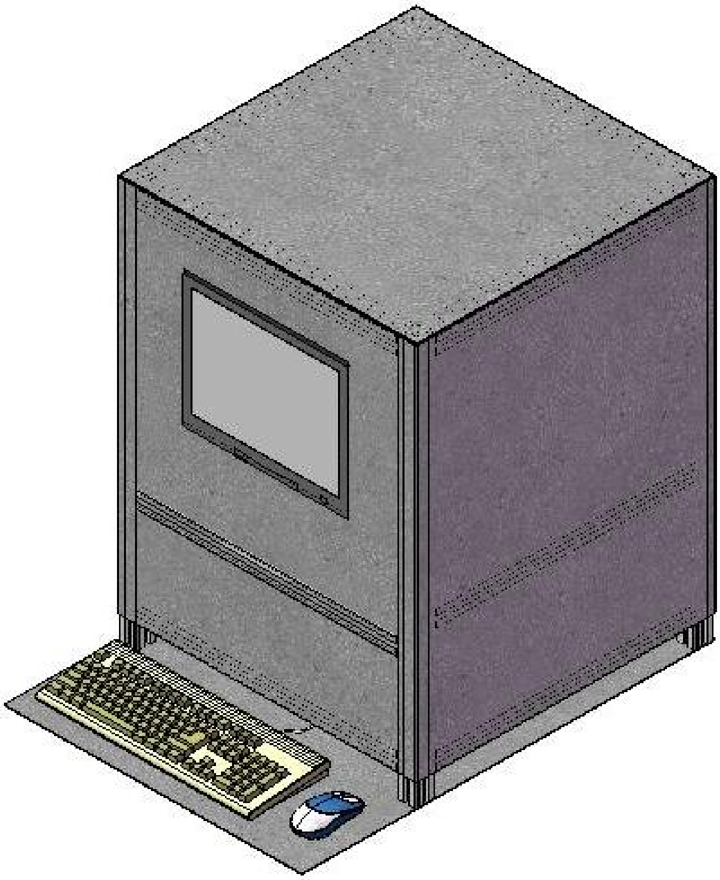


Figure 5.3 Assembly View of the Device

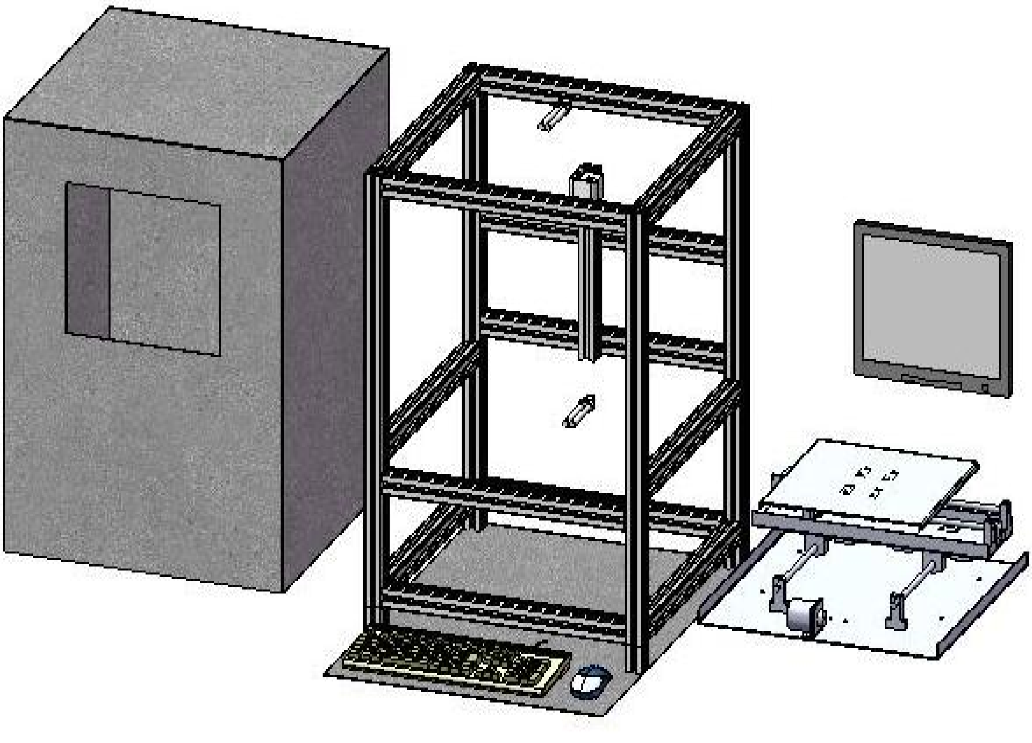


Figure5.4 Illustration of the Device in Separate Parts

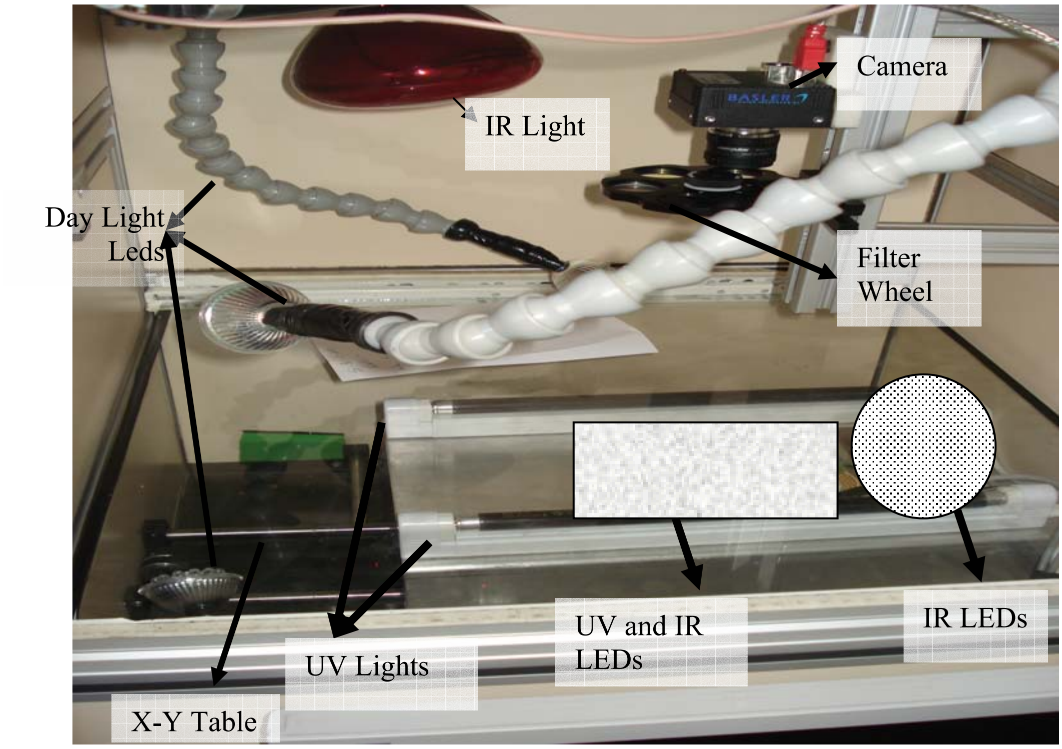


Figure 5.5 Parts of the device showing the Table, Lights, Camera and Filter Wheel

(a) (b)

Figure 5.6 General View of the Device (a) and Light Details (b)

5.4 Application Examples

General applications which can be separated on different types of documents are presented in this section. In application, the non-destructive tests are applied as; IR luminescence, UV application, black and white photography with various filters. The numbers of applications can be increased. However, these applications will be repetitive for examiners. Examples are chosen with forensic experts, also from questioned document books and their seen applications. Many sessions are performed with experts in this field.

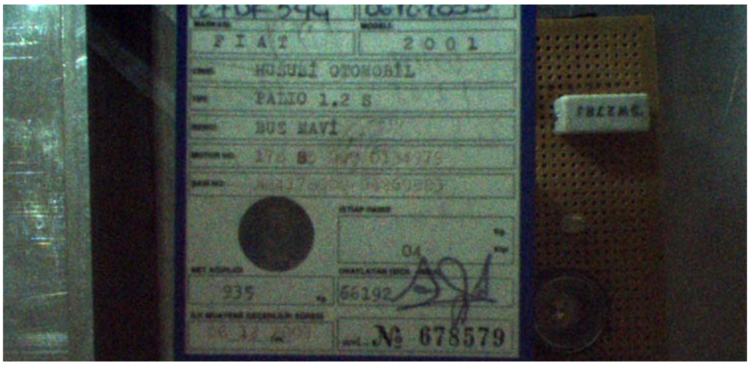
The first application; basic invisible ink test is shown on the banknote. Figure 5.7 (a) and (b) illustrate a banknote and its processed form respectively. UV lightening is used on the banknote.

(a)

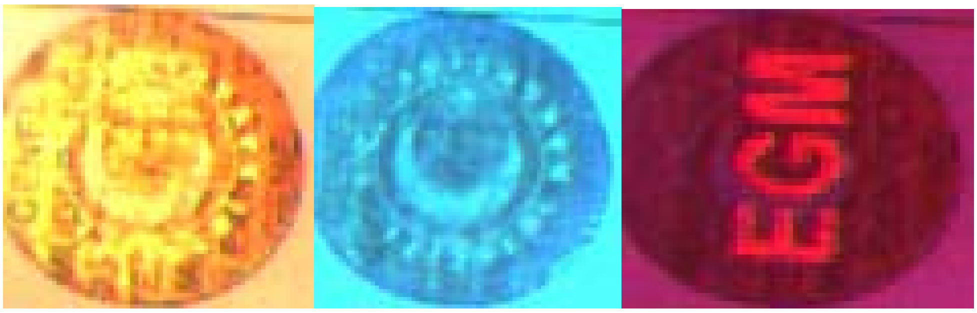
(b)

Figure 5.7 Banknote test (a) Original, (b) Processed

The second example is the hologram on the vehicle license. Three different images are available on the documents which are shown in Figure 5.8. UV, IR and visible filter with different daylight angle are used on the license.



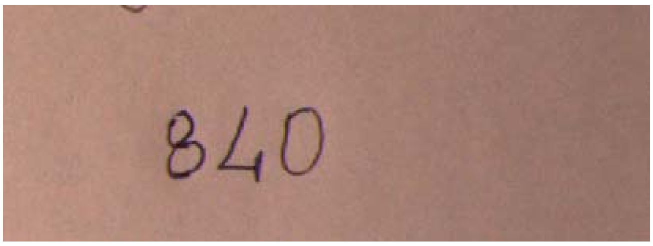
(a)Original



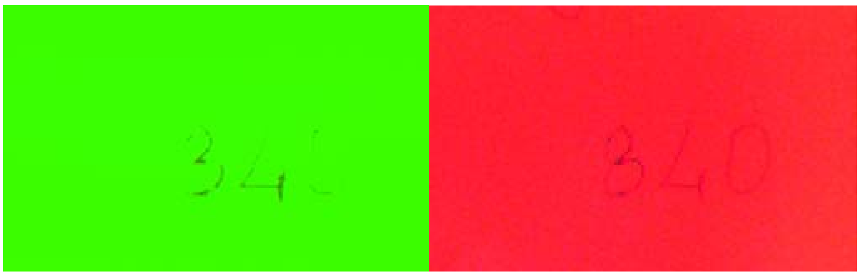
(b) Sloped daylight (c) UV light (d) IR filter

Figure 5.8 Hologram test

The next example is related with the mostly seen application of questioned document, where the original amounts are changed or new numbers are added on the document by the impostors. IR luminescence photography reveals the entries on document made with different pens. This is the case mostly seen in cheques and other important legal documents. Figure 5.9 (a), (b) and (c) shows how number "34" is written as "840" in original document to mislead the reader.



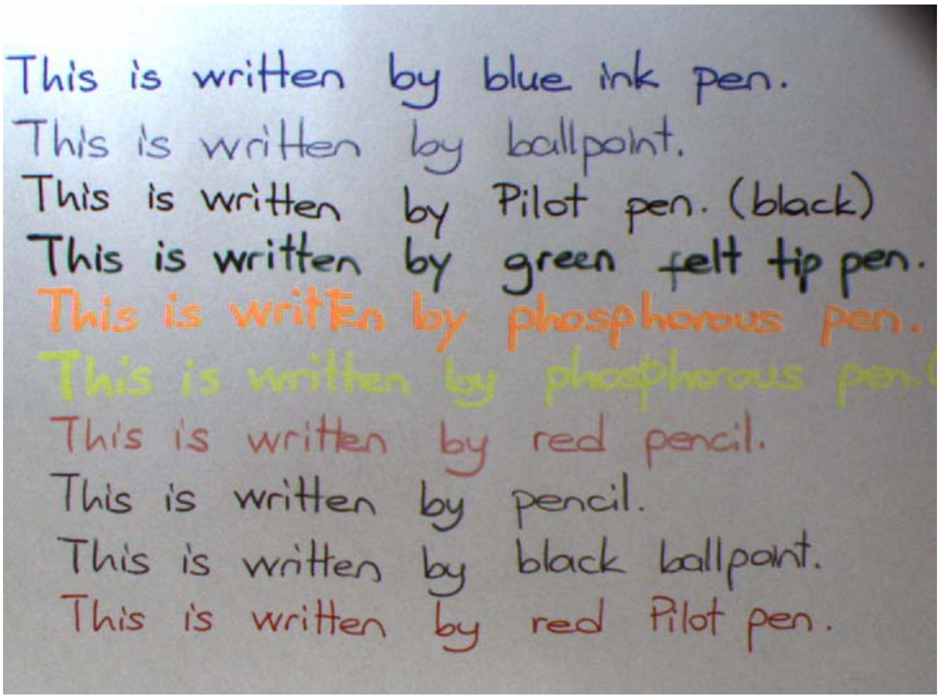
(a) Normal Document



(b) Near IR (c) IR

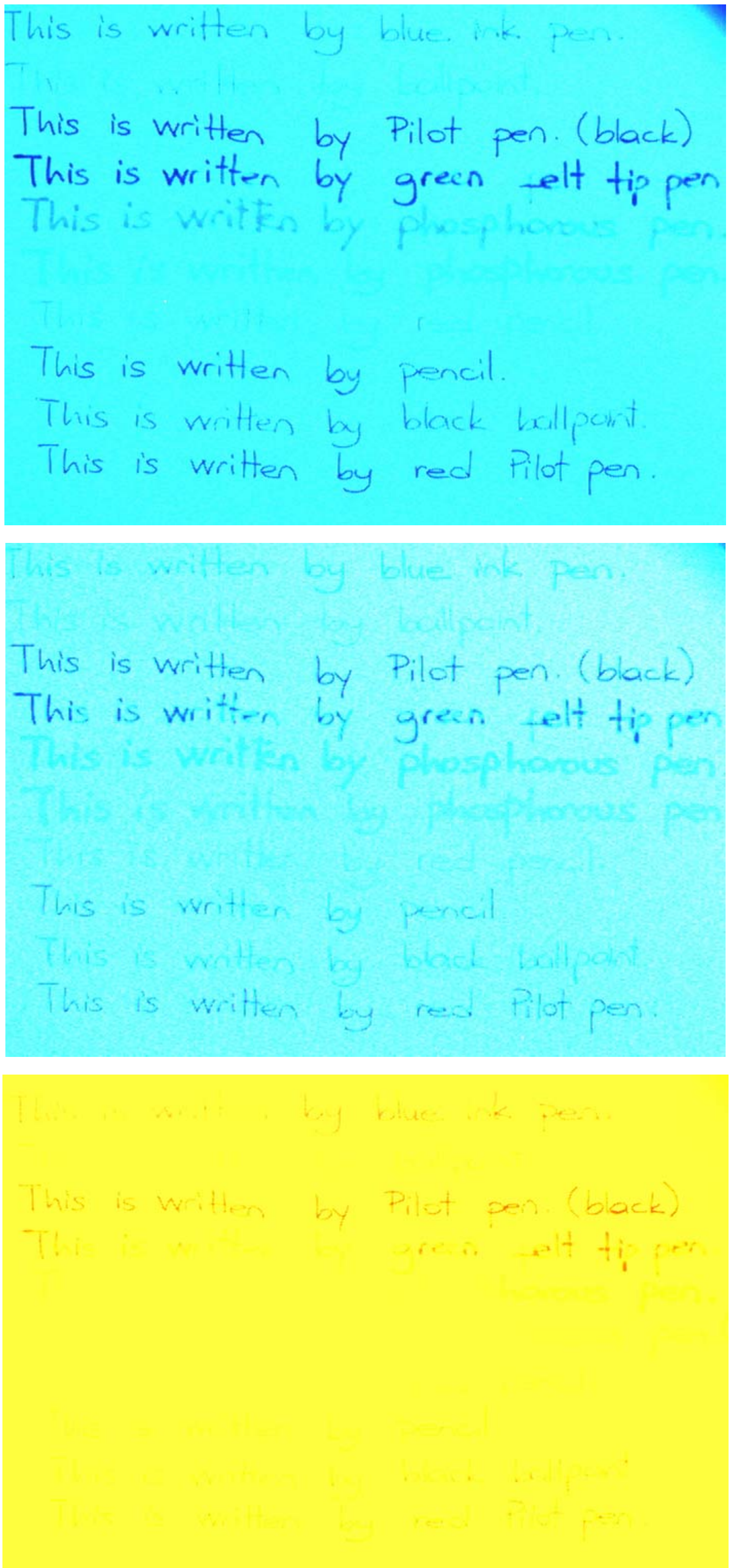
Figure 5.9 (a), (b), (c) Document destruction and IR luminescence

Different types of inks on the document are shown in Figure 5.10. The document is prepared with different colour and types of pens. Phosphorous, felt tip pen, different kinds of blue, red and black pens are used. Phosphorous and felt tip can be seen clearly under UV light. The others become invisible under IR light source and by filter. Camera settings and colour parameters are also adjusted while acquiring the images for all examples. Number of examples of the questioned documents can be extended. Here the main concentration is done to show the device operates successfully.



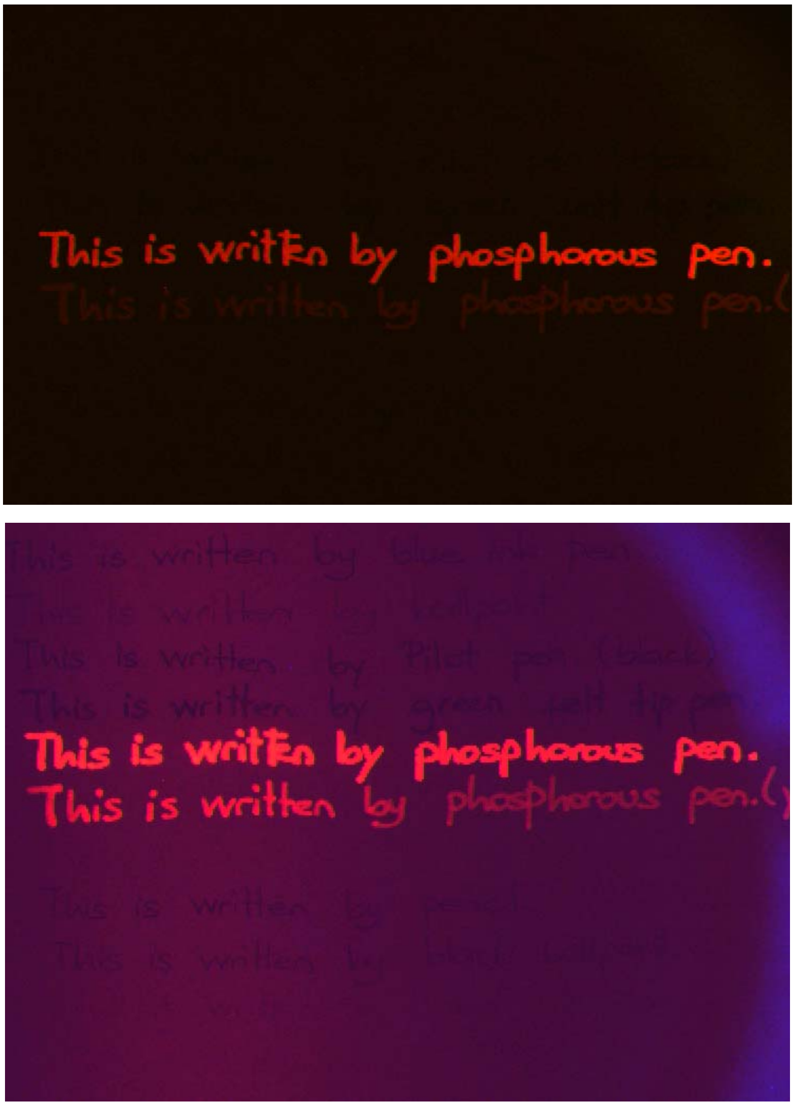
(a) Original

Figure 5.10 Ink test with different pens



(b) IR Light view with different wavelength

Figure 5.10 Ink test with different pens



(c) UV Light view

Figure 5.10 Ink test with different pens

CHAPTER 6

APPLICATION OF OFF-LINE SIGNATURE VERIFICATION

6.1 Introduction

The verification process proposed in this study is composed of four steps. Firstly, signature images obtained from seven volunteers are scanned (*data acquisition*) and image processing is applied to make images suitable for extracting features (*pre-processing*). Each pre-processed image is then used to extract relevant geometric parameters (*feature extraction*) that can distinguish signatures of different volunteers. Finally, the proposed verification algorithm is tested on the database that includes 1350 skilled and genuine signatures taken from 25 volunteers.

A forgery may be prepared in several ways. Simple definitions are given with the types of forgeries used in literature. These definitions will be used throughout the chapter. Professional impostors imitate the genuine signatures. Therefore, the hardest verification problem is "*skilled forgery*". When a person signs the name of victim with his/ her own style to generate a forgery is known as "*random forgery*". The other type is the "*unskilled forgery*" which is copied by inexperienced signer who used his/her own style without any knowledge of the spelling. The rejection rates of the random and unskilled forgeries are higher than skilled one. Therefore, skilled forgery is chosen for this application. This chapter includes SV process with test results using the proposed algorithm PSO-NN together with statistical analysis.

6.2. Signature Verification

6.2.1 Data Acquisition

"Grupo de Procesado Digital de Senales"(GPDS) database[72] and also new signatures are collected from Mechanical Engineering Department, Gaziantep University. Scanner views with 300dpi and 8 bit are used for collecting signatures. GPDS consists of 160 sets of signatures; and for each set, 24 samples of genuine and 30 samples of forgeries were available. In this study, 25 new sets of signatures have been used. Sample of Genuine and skilled forgery taken from the database is shown in Figure 6.1.

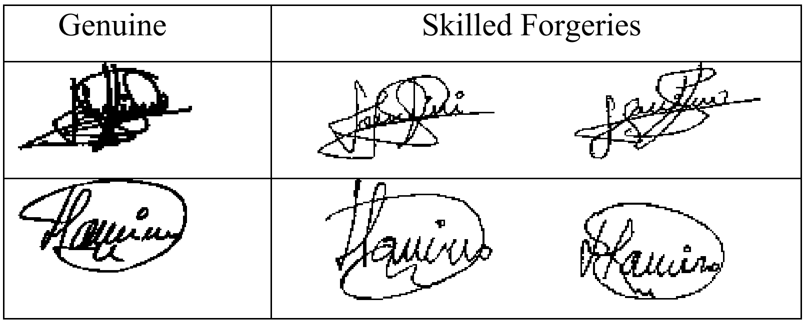


Figure 6.1 Signature samples from the database

6.2.2 Pre-processing

The scanned signature image may contain spurious noise and has to be removed to avoid errors in further processing steps. The user needs to specify a local region of most interest. A cropping tool is provided so that the user can scissor-out a region of interest (ROI) from the original document. All of the analysis based on the selected ROI is done. The image is converted into a binary image, thereby isolating the foreground comprising the signature from the background. Normalization, area cutting, resampling, erode-dilate and thinning operations are applied on signature respectively. These operations are adopted on the software with a preparation unit. Signature is then further used for feature extraction.

6.2.3 Feature Extraction

Newly developed and already existing feature extraction methods are used for distinctive features of handwritten signatures in this part. First of all, two types of image division can be obtained on the signatures in SV toolbox. A partially new technique; "*the vertical equal size distribution*" can be applied onto the image.

Signature is divided in equal size box vertically or horizontally. "*The partially new*" means that the division is applied on one direction in the original literature. In this study, the division direction can be chosen by the user for both horizontal and vertical directions which is thought to be an important contribution. Dimension of the boxes can be chosen from SV toolbox. The other approach is "*equal size distribution*": Signature is divided as the same dimension pixel size for the each column and row which is available application in the literature. After division process, extraction is applied automatically on to the image. Width and height ratio, position of centre of gravity in each part is calculated. Normal angle with respect to centre of gravity of signature is extracted.

Figure 6.2 (a) and (b) illustrate the general interface of software and the extracted signatures. In the ability of the program, many parameters can be adjusted by the user. To obtain better performance of the algorithm, the different numbers of division applications are applied on to the signatures. The results are shown in Section 6.3.

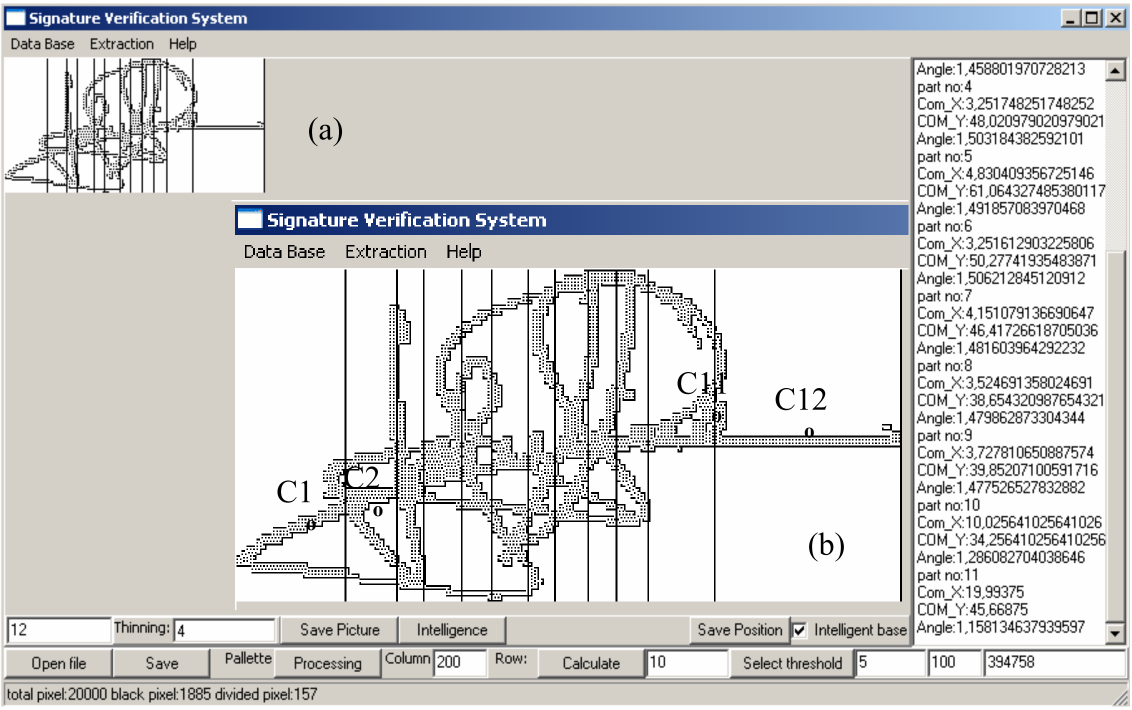


Figure 6.2 (a). SV toolbox used in verification (b) Sample Signature used in extraction, C1, C2,…C11 and C12 are the centres of gravity for the divided parts

6.2.4 Verification

A verification approach based on PSO-NN is developed to recognize the genuine signatures from forgeries with reliable accuracy. Mathematical background of the particle swarm optimization (PSO) and neural network (NN) were given in Chapter 3. First of all verification process must be performed for the training section. Then parameters of the proposed method are adjusted which are number of particles (variable), dimension which is constant for each application for example dimension is 608 for 18 input, and 32 nodes for the hidden layer , the number of parameters and the constants for NN and PSO (λ, c_1,c_2,etc…) in training process. After training, weights of the network are obtained in data file that is used in testing of the algorithm. Finally, the program must be run for the testing part of the signatures.

6.2.4.1 Normalization Procedure for input values

In order to normalize the experimental data to the range [0, 1], the value $y(x)$ at each (x) point was normalised to according to equation (6.1) for all input and output points. Table 6.1 (a) and (b) illustrate a set of normalized input values of a sample signature for verification process.

$$y(x) = \frac{y - y_{\min}}{y_{\max} - y_{\min}} \qquad (6.1)$$

Where;

$y(x)$ = Normalized value (between 0 and 1)

y = Original value

$y_{\min}$ = The minimum allowed value

$y_{\max}$ = The maximum allowed value

Table 6.1 Set Of Normalized Input Values for a Sample Signature

	1	2	3	4	5	6	7	8	9	10
1	0,000	0.000	0.576	0.688	0.370	0.803	0.591	0.738	0.550	0.791
2	0.000	1.000	0.465	0.730	0.695	0.712	0.498	0.585	0.419	0.342
3	0.000	0.715	0.601	0.469	0.486	0.533	0.522	0.539	0.594	0.794
4	0.678	0.527	0.504	0.557	0.368	0.490	0.000	0.000	0.000	0.611
5	0.691	0.000	0.000	0.344	0.000	0.000	0.000	0.000	0.000	0.000

(a)Grid Normal Angle

Input Value	Normalized Value
Part No 0	**Part No 0**
X : 20.441176470588235	0.637394
Y : 58.215686274509804	0.958322
Angle : 1.233116671032329	0.770747
Part No 1	**Part No 1**
6.561904761904762	0.118349
44.60952380952381	0.692032
1.424747191621299	0.954545
Part No 2	**Part No 2**
6.425742574257426	0.113257
39.287128712871287	0.587866
1.408673358755032	0.939128
Part No 3	**Part No 3**
7.235849056603774	0.143552
38.792452830188679	0.578184
1.38638826755382	0.917754
Part No 4	**Part No 4**
7.151515151515152	0.140398
34.121212121212121	0.486762
1.364195435423524	0.896468
Part No 5	**Part No 5**
17.423423423423423	0.524539
21.261261261261261	0.235076
0.884282791698381	0.436171

(b) Equal Size Distribution

6.3 Application Results

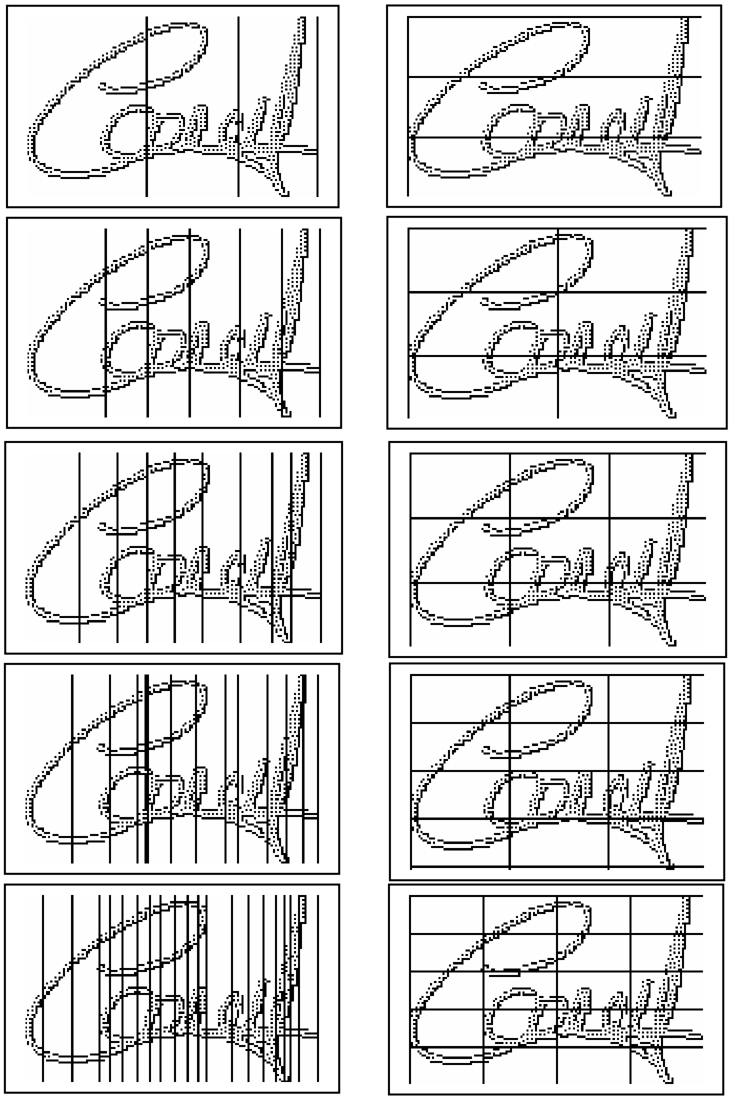
It is difficult to compare the results of verifications with the literature, as many different databases have been used for the application. As mentioned previously, 25 sets of GPDS database have been performed in this study. Forgery signatures also include the skilled signatures.

Different number of inputs have been generated and tried for verification process. In this study two different division techniques can be applied onto the signature. The same signatures set are tried with 3, 6, 9, 12, and 20 parts. Numbers of divisions are chosen randomly, in order to compare small and large parts. One of the set is divided vertically with equal size. The other one is divided with square constant sizes such as (3x1, 3x2, 3x3, 4x3, and 5x4). Additionally, different number of particles (25, 30, 40, 50) and iterations (1000, 2000, 5000, 10000) are also applied onto the same signatures. The number of particles and iterations are adjusted with trial and error method.

Figure 6.3 illustrates the example of genuine and forged signature respectively. Figure 6.4 shows an example of extractions. Application results are then given in Table 6.2. Vertically divided samples have better results than meshed signatures according to the comparison results. Additionally, increasing the number of divisions and particles are positively affecting the accuracy of the system. For example, 5 genuine are correctly verified and 9 skilled forgeries are correctly rejected in vertical 3 part. However, 4 genuine signatures are misclassified and 10 forged signatures are correctly rejected.

During application, 25 sets of 54 different signatures have been used while verification. Numbers of 24 genuine and 30 forgery signatures have been performed for each set. Genuine 15 signatures and 16 forgery signatures are trained for neural network training. PSO-NN algorithm has 40 particles and 5000 iteration. Input nodes (18) are adapted for each input set and hidden layer (32) nodes adapted system with trials in the training section. Parameters of the network have been used with 0.8 learning rate and λ is 1. Results have been tested with rest of the signatures. Trials have been executed on a P4 2800 MHz CPU, 512 MB PC.

Figure 6.3 Genuine and Forgery signature



(a) (b)

Figure 6.4. Illustration of extracted signatures with different number of parts
(a) 3,6,9,12,20 divisions with vertical equal size distribution,
(b) 3,6,9,12,20 parts with respect to horizontal and vertical division

Table 6.2 Comparison of different number of divided parts with respect to number of iterations

	Genuine						Skilled Forgery					
	Accepted(True)			Rejected(false)			Accepted(False)			Rejected(True)		
No of Iter.	**25**	**30**	**50**	**25**	**30**	**50**	**25**	**30**	**50**	**25**	**30**	**50**
Vertical 3	5	5	5	4	4	4	6	5	5	8	9	9
Meshed 3-1	4	4	4	5	5	5	6	7	7	8	7	7
Vertical 6	7	7	7	2	2	2	5	5	5	9	9	9
Meshed 3-2	6	6	7	3	3	2	5	5	4	9	9	10
Vertical 9	7	7	7	2	2	2	4	3	3	10	11	11
Meshed 3-3	6	7	7	3	2	2	5	4	5	9	10	9
Vertical 12	7	8	8	2	1	1	4	4	3	10	10	11
Meshed 4-3	6	7	7	3	2	2	5	4	4	9	10	10
Vertical 20	7	8	8	2	1	1	4	4	4	10	10	10
Meshed 5-4	7	8	8	2	1	1	5	4	4	9	10	10

6.3.1 The False Rejection Rate (FRR) and The False Acceptance Rate (FAR)

The probability that the system declares incorrectly a successful match between the input pattern and a non-matching pattern in the database [73]. It measures the percent of invalid matches. The false rejection rate (FRR) and the false acceptance rate (FAR) for a biometric device are defined as; the distribution of FAR and FRR is shown in Figure 6.5. Equations (6.2) and (6.3) gives the determination of FRR and FAR respectively.

$$FRR = \frac{\text{number of failed attempts at authentication by authorized users}}{\text{number of attempts at authentication by authorized users}} \tag{6.2}$$

$$FAR = \frac{\text{number of successful authentications by impostors}}{\text{number of attempts at authentication by impostors}} \tag{6.3}$$

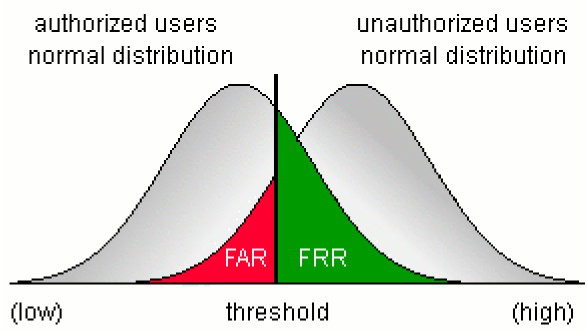


Figure 6.5 FAR and FRR on Normal distribution graphs

Both FAR and FRR are dependent on the adjustable adopted threshold. A higher threshold is caused to increase FAR while FRR will decrease. When the value of threshold is decreased, the proportion FAR will decrease, while FRR increases [74]. Equal Error Rate (EER) is the intersection point of FAR and FRR on the coordinate system. This relationship is illustrated in Figure 6.6. Verification results can then be seen in Table 6.3. According to the results, verification system has 26.85% FAR. This means that 94 skilled forgeries are accepted incorrectly from 350 forgeries. On the other hand, the verification system has 17.33% FRR which tells 39 genuine samples are rejected in 225 signatures by mistake. The average error rate for verification is 22.09%. Thus the experiments on data base have shown comparable performance. Table 6.4 illustrates the reliability of a system for 25 samples. Results of samples are given one by one. Probabilistic approaches are always used for utilizing results.

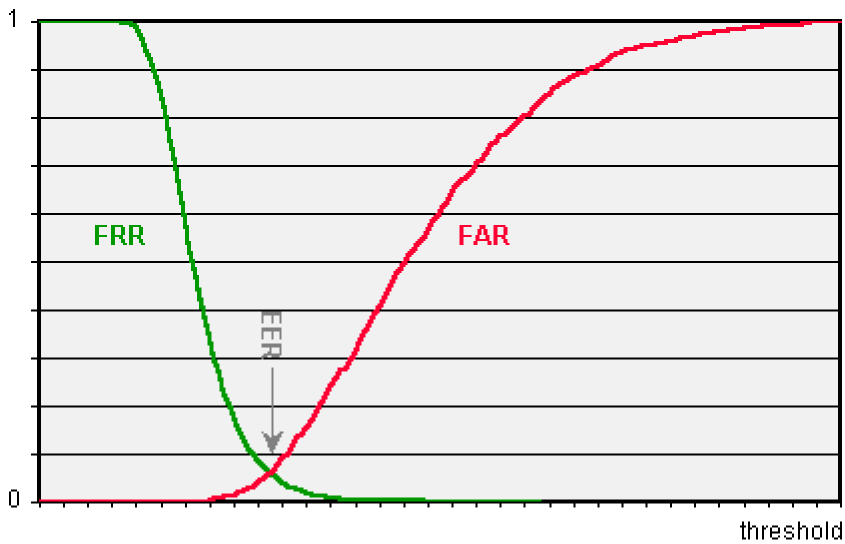


Figure 6.6. FAR - FRR Diagram

Table 6.3 Verification Results of Signature Database

	Tested	Accepted	Rejected	Results in %
Skilled	350	94	256	26.85 FAR
Genuine	225	186	39	17.33 FRR
	Overall Accuracy			22.09

Table 6.4 Verification Results for 25 samples

	Genuine		***Skilled Forgery***	
No of Sign.	**Accepted**	**Rejected**	**Accepted**	**Rejected**
1	8	*1*	3	*11*
2	7	*2*	5	*9*
3	8	*1*	4	*10*
4	8	*1*	3	*11*
5	6	*3*	6	*8*
6	8	*1*	3	*11*
7	8	*1*	4	*10*
8	7	*2*	3	*11*
9	8	*1*	4	*10*
10	7	*2*	3	*11*
11	7	*2*	3	*11*
12	6	*3*	5	*9*
13	8	*1*	3	*11*
14	8	*1*	3	*11*
15	8	*1*	4	*10*
16	7	*2*	5	*9*
17	8	*1*	3	*11*
18	6	*3*	4	*10*
19	8	*1*	4	*10*
20	7	*2*	5	*9*
21	7	*2*	4	*10*
22	8	*1*	3	*11*
23	7	*2*	4	*10*
24	8	*1*	3	*11*
25	8	*1*	3	*11*
Total	**186**	***39***	**94**	***256***

6.4 Comparison of Verification Accuracies

Successful verification rates seen in literature are compared with PSO-NN method applied. In signature verification, comparisons can be made with the error rates obtained, or verification rates seen or conducting hypothesis testing. By observing the results obtained in Table 6.4, some studies are chosen to be a base for performance calculation. Verification rates taken from studies are presented as the following.

Verification efficiency of PSO-NN is compared with the Resilient Backpropagation (RBP) neural network and the Radial Basis Function (RBF) network [75]. Armand et al. have been studied off-line SV using an enhanced modified direction feature (MDF) with NN approaches. MDF is defined as combination of direction feature and transition feature which are described in reference [76]. Addition to MDF, centroid feature(C), tri surface feature (T), length feature (L), six fold-surface feature (S) and the best-fit features (F) have been used with different applications. GPDS database (44 samples), 135 input values from each signature have been used for verification process. The genuine set, 20 samples of each signature have been used for training, 4 for testing. For the forged signatures, 25 samples of each signature have been used for training, 5 is applied for testing. Number of hidden layer (40) and number of iteration (10000) have been chosen during experimentation. Verification rate for RBP is 88.64 % with 1.16% error rate using a single neural network. The second one is the RBF which is 89.77% verification rate and 1.22% error rate.

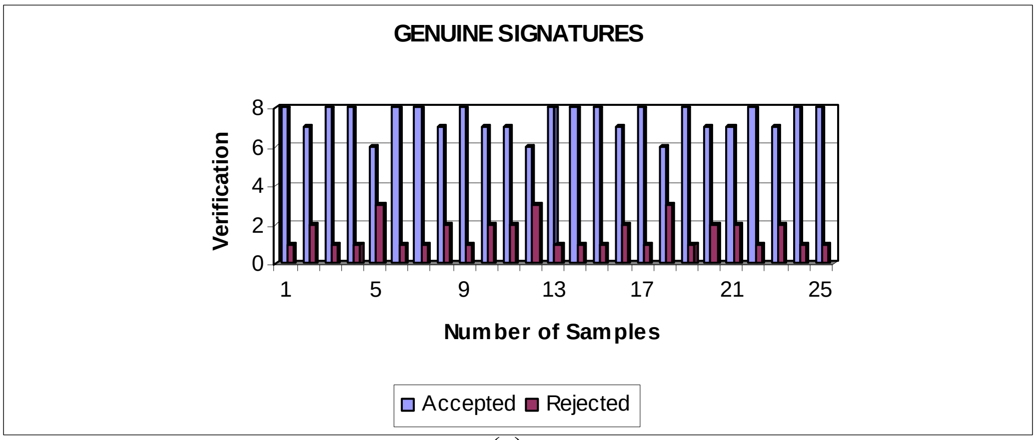
Due to the differences in experimental methodology and database size chosen, the comparisons between studies are not accurate. The other system performance which is used in skilled forgery verification has been seen as 23.18 % FAR, and 20.62 % FRR [32]. Shirari et al. have been used Bayesian and k-nearest classifier in the off-line SV. Overall accuracy of system is given 78.1 %. This means that the average error rate for verification is given 21.9 %. Performance of the system has been tried on the 55 writers with 25 genuine and 20 skilled forgeries. The general approach for commenting on result will be probability of the verification rates. Therefore, one statistical method is applied on the verification results to make a decision in the next section.

6.5. Statistical Analysis

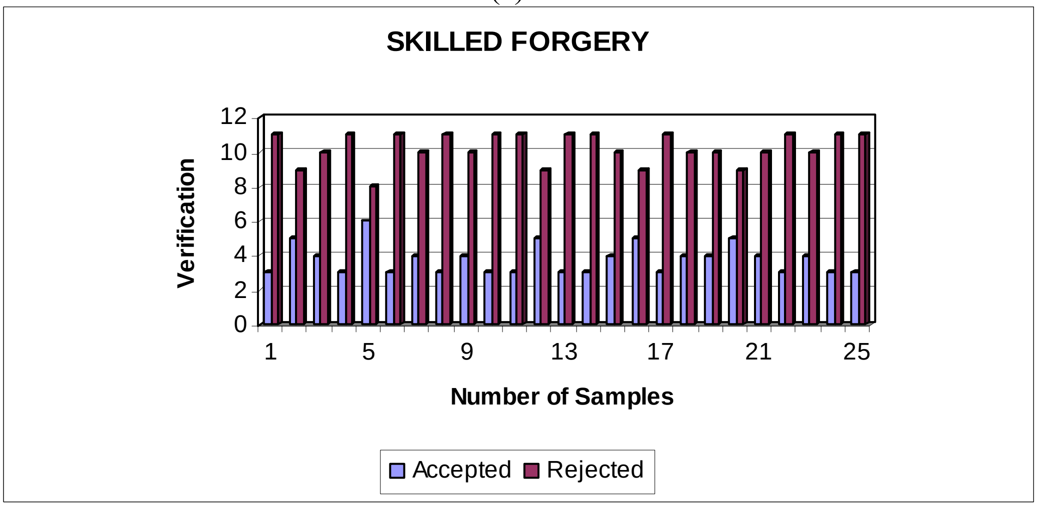
Statistical methods are extremely important in engineering studies. Large amounts of data can be interpreted and utilized for the applications of interest. Before using a data set for any engineering application, its quality must always be examined before making a decision. The requirement is always to get a conclusion from the data available.

Initially a histogram plot is presented where each sample is studied with equal bins. Here '*population*' refers the entire collection of objects, measurements, observations. GPDS data base is *population* referred in this study. Similarly, a sample is a subset of population on which the method is applied, 25 sample set are performed. The data in Table 6.4 can be visualized better by plotting them in the form of bar graph, called *histogram.* The histogram shows the data much more clearly than the tabular method given in Table 6.4. Therefore, graphical representation of the distribution can be arranged as bins '*genuine*' and '*skilled forgery*'. They are plotted as number of samples to values '*accepted*' and '*rejected*'. Figure 6.7 (a) and (b) show histogram plot of genuine and skilled forgery rows obtained.

There are also many possible methods to compare the distributions. Srinivasan et al. [77] have addressed signature verification using Kolmogorov-Smirnor (KS) test [78] and its performance results were presented with figures. The Chi-Square test is an alternative to Anderson-Dawling (AD) and KS, goodness of fit tests. The KS and AD tests are restricted to be used in continuous distributions. Thus the Chi-square is applied to a discrete distribution here.



(a)



(b)

Figure 6.7 Histogram plots for genuine and skilled forgery samples

6.5.1. The Chi –Square (χ^2) Test

The Chi-square (χ^2), goodness of fit test is considered to see how well the signature data set "fits" or "agrees" with probability distribution function. A data set is believed to be matched by a completely specified finite discrete probability distribution in this test. This test is applied to make decisions where chance also plays a role. It is also applied to binned data where the data put into classes. Since signature is a behavioural biometrics, change in age and health condition is a factor in the signature produced. In this test, the hypothesis to be tested is called '*the null hypothesis'* and a counter corruption is called '*the alternative hypothesis*'. [79, 80, 81]

The Chi-square test is based on a calculation of the quantity defined by;

$$\chi^2 = \sum_{i=1}^{n} \frac{[(observedvalue)_i - (\exp ectedvalue)_i]^2}{(\exp ectedvalue)_i} \quad (6.3)$$

Where n is the number of cells or groups of observations. In this study, calculations have been made to see how the actual calculation results match the expected one. The probability is defined by *'p'* and is calculated using Table A.1 [79].

In Table A.1, *F* refers to degree of freedom in the measurement, or observation as

$$F = n - k \quad (6.4)$$

Where k is the number of imposed condition on the expected distribution. This test is sensitive to the choice of k.

6.5.2. The Chi-Square Test on Signature Database

Having applied PSO-NN method, verification results are presented in Table 6.3 for *'genuine signature'* and '*skilled forgery*'. They are performed for 25 different samples, in which all of them can be seen in Table 6.4 in the explored manner. Here the Chi-square test is applied for both signatures. Initially, '*genuine signature*' data are taken; the values of interest are given in tabulated manner. Total 225 genuine signatures are taken, the Chi-square is computed according to equation (6.3), and Table A.1 is consulted for the probability.

In section 6.3, Table 6.4 shows the verification results for 25 samples, where in each samples, genuine signatures are taken '9' and skilled forgeries are taken '14' signatures during the test. The Chi-square is also applied to Table 6.4 to see how this information is conveyed in 25 samples. In each, a check is initially performed such that a certain number of samples for statistics to apply. For this test, the accepted minimum number of each cell is 5; therefore by consulting Table 6.4, same samples are to be redefined. The test statistics show the characteristics of the test. When the hypothesis is accepted, the statistics follows the normal distribution, when the statistics are significant, the hypothesis are rejected (Significance levels of 0.10, 0.05 or 0.01) [79].

Hypothesis: From the data taken, would you conclude that 'signatures are genuine'?

	Observed	Expected
Accepted	186	**112.5**
Rejected	39	**112.5**
	225	**225**

For these values χ^2 is calculated as;

$$\chi^2 = \frac{(186 - 112.5)^2}{112.5} + \frac{(39 - 112.5)^2}{112.5} = 96.04$$

Two observations; accepted and rejected results can be seen, n = 2, k = 1 and *F*=1. By looking at Table A.1, P<0.005, a decision can be made that, the signatures are 'genuine'.

Similarly, additional data is used for testing 'skilled forgery', using Table 6.3 again. Total 350 signatures are applied. Two observations are taken as accepted and rejected. Where n=2, k=1, *F*=1.

Hypothesis: From the data taken, would you conclude that 'signatures are forgery'?

	Observed	Expected
Accepted	94	**175**
Rejected	256	**175**
	350	**350**

$$\chi^2 = \frac{(94 - 175)^2}{175} + \frac{(256 - 175)^2}{175} = 75$$, From Table A.1, P<0.005

There is no absolute check in this method. A confidence level must be applied at the beginning, and then the final acceptance or rejection will be left to the judgement or expert. It can certainly give an idea for the final decision.

A misplaced data point can also be eliminated to improve the data of evidence. There are number of statistical methods for rejection of data points. The basis is generally taken to eliminate values that have low probability of occurrence. In the same database, elimination of some samples, affects the verification results. For example; in this study, Table 6.4 is examined in detail, some samples can be reconsidered, 3 samples giving outcome 6-3 are not taken into consideration in '*genuine*' row, 22 samples with 198 signatures are taken. Similarly, one outcome 6-8 is not taken into consideration in *'skilled forgery*', analysis are carried out for 24 samples with 336 signatures. It is important to note that, the verification results given in Table 6.3 change more than 2.5 % for both signatures. This directly affects overall accuracy of the verification. By eliminating the misplaced data, rate of success can be changed for both *genuine* and *skilled forgery*. If random forgery has been applied, the obvious point was that the rate of success would be significantly different. Since our objective in this verification system was to recognize the genuine from the skilled forgeries, a success at this time is certainly obtained again together with a check on the level of uncertainty proposed.

6.6 Remarks on Verification Results

Artificial Intelligence techniques NN, in particular, an evolutionary algorithm based on Swarm Intelligence PSO are used for SV system in this study. Overall accuracy of the system is nearly seen as 78 % (22 % mismatches). Series of results are subjected to the Chi-square test to check the validity of the assumed function. Quality of uncertainty is studied using previous marks [82] in biometric studies. Levels of uncertainty can be classified as; low, medium, high, and very high uncertainty level. Table 6.5 shows levels of uncertainty which is defined by Yanushkevich et al [82] in biometric studies. This table enables classification of conditions for verification in terms of uncertainty. According to the table, Strength of evidence changes. The verification rate found in this study is included in '*ideal conditions*'.

Table 6.5 Levels of Uncertainty

Ideal Condition	***Low level of uncertainty (< 30 %)***	***Biometric system works***
Medium Condition	Medium level of uncertainty (about 50 %)	**Decision is not certain (not conclusive)**
Hard Condition	High level of uncertainty (about 70 %)	**Biometric system is unreliable**
Very Hard Condition	**Very high level of uncertainty (about 90 %)**	**Biometric system fails to make a decision**

CHAPTER 7

CONCLUSION

7.1 Present Study

In this thesis, the study is mainly carried out in two parts; as ‘off-line signature verification (SV) with PSO-NN’ and ’design and implementation of questioned document device’. Initially, to perform the first part, handwritten signatures are collected from an available database with preparation of SV toolbox. An improved verification method; PSO-NN is adopted and applied on the signatures. The PSO is also used to train neural network system. The performance of the method is tried on different database in many applications. Finally, GUI program is named “IMPQD” is prepared for the questioned document investigation to be used with, so called “BIO-BOX”. This device is designed and manufactured in Gaziantep University, Department of Mechanical Engineering, System Dynamics and Control Laboratory.

Chapter 1 is presented an introduction to Biometrics and layout of the thesis. A literature study on offline SV is given in Chapter 2 with verification methods used. Mathematical background necessary for the study is presented in Chapter 3, with the proposed method PSO-NN. In Chapter 4, IMPQD software is introduced with its ability and hardware requirements, also with image processing tools. BIO-BOX is then described. Assembly details of the questioned document device with lightening information and filters are studied in Chapter 5 with application examples on the device. Application on SV toolbox is included in Chapter 6. Lastly the study is concluded here, in Chapter 7 with recommendations for further work.

7.2 Observation on Signature Verification

Pattern recognition systems have never been used at such large scale. Therefore it has become necessary to carry out person recognition in many fields in social life; finance, health, transportation, law, security, access control etc. Signature verification is a difficult but tractable problem. This work has got also worldwide importance and impact.

Generally it is possible to understand if a human characteristic can be used for biometrics in terms of the following parameters: *Universality, Uniqueness, Collectability, Performance, Circumvention, Permanence, and Acceptability*. Table 7.1 shows a comparison of existing biometric systems in terms of parameters mentioned. Signature is highly preferable with respect to C*ollectability* and A*cceptability*. Therefore the studies on signature verification have a great importance. Much progress has been performed in SV recent years. However a model based statistical approach is not available.

Table 7.1 Comparison of various biometric technologies [83]

Biometrics	Universality	Uniqueness	Permanence	Collectability	Performance	Acceptability	Circumvention
Face	H	L	M	H	L	H	L
Fingerprint	M	H	H	M	H	M	H
Hand Geom.	M	M	M	H	M	M	M
Keystrokes	L	L	L	M	L	M	M
Hand veins	M	M	M	M	M	M	H
Iris	H	H	H	M	H	L	H
Retinal scan	H	H	M	L	H	L	H
→ **Signature**	**L**	**L**	**L**	**H**	**L**	**H**	**L**
Voice	M	L	L	M	L	H	L
Facial Thermograph	H	H	L	H	M	H	H
Odor	H	H	H	L	L	M	L
DNA	H	H	H	L	H	L	L
Gait	M	L	L	H	L	H	M
Ear Canal	M	M	H	M	M	H	M

In this study, the signature verification process is performed with off-line signature images, which are obtained from GPDS database by scanning the signatures from documents. This procedure is certainly different from on-line signatures which are captured simultaneously. The proposed verification algorithm, PSO-NN is tested on the database that includes 1350 skilled and genuine signatures taken from 25 volunteers. Only the verification process requires the C compiler which means that IMPQD has an execution file. However the variables of the verification process require adjustment with compiler. The applications and results are given on skilled forgeries. The flexible SV toolbox is then adopted on the IMPQD. The user can adjust the values of extracted features, the types of extraction, the size of signatures and etc.

The PSO-NN algorithm is developed and implemented on the verification process herein. The abilities of the particle swarm are adopted to train network. The performance of the algorithm is satisfactory. Many factors affect the performance of the PSO. The number of particles in the swarm has a significant effect on the run-time. Dimension and convergence rate of the algorithm is the other factor to be considered during its application.

In Chapter 6, the accuracy of this SV system is presented in terms of False Rejection Rate (FRR) and False Acceptance Rate (FAR) referring to literature available on the subject. Statistical analysis of the results are also performed, the Chi-square method is applied to the problem of SV. Two separate distributions; one for genuine signatures and other for the skilled forgery are studied to obtain a probability to make a decision. The result was that of giving overalls 22% uncertainty for database taken. In reference studies, this value is accepted as the biometric system works. The Chi-square test has also shown a highly acceptable probability value.

Since variations in environmental conditions can happen, 100 % success is never obtained in biometric application. This result is much lower for the behavioural biometrics, especially in signature analysis. For example; signatures can be written under influence of alcohol or drug, some with severe illness or by elderly people. So the level of correspondence must be defined by using a threshold in all biometric applications. This is also applicable to off-line signature analysis.

7.3 Observations on Questioned Document Investigation

There are commercially available document examination devices. Device of Foster Freeman is VSC5000 (Video Spectral Comparator) [84]. It represents a digital imaging system for questioned document investigation. MST-1 Forensic Spectral Micro Scanner is the device of MS macro system [62]. They are both used for detecting security features and revealing alterations on also examining invisible information on documents.

A new and innovative design is applied for the questioned document investigation device. The main body construction of the device is changed. The device is made automatic using X-Y table driven by stepper motors. It is designed for A4 documents. Two sided lightening is used for illumination. LEDs and lambs are all used together for the illumination. The flexibility of light sources is achieved on the system. Finally IMPQD software is embedded on the device control. A user friendly, fast and flexible solution is presented. An analysis of documents is certainly performed for their originality in question. An original contribution is that, SV can also be performed in the device, BIO-BOX. This makes it valuable for many different applications on biometric basis. In questioned document devices in use, paper handling and check has been done manually by the experts. BIO-BOX gives the user opportunity to handle both questioned documents and/or with SV toolbox. Software can be used without device, only building execution files separately just for the purpose of SV. Therefore a complete flexibility is provided with this design.

7.4 Further Studies

Reliability and performance of the SV can be increased by adopting different types of extraction methods on the system. Improvements and methods will always go on to supply the correction rate 100%, but this will not be happened. Addition to extraction process, the new and efficient swarm algorithms (Ant colony or Bees algorithm) can be performed for verification process. Hybrid approaches which online and offline inputs can be used together on the SV.

Addition to the known logo or format the cheques, passports or others, the originality of the bank cheques, passports or other official documents can also be checked with preparation of the signature database. National signature database can be prepared and embedded on to the questioned document device. However, it requires highly protected legal procedure. Small size of devices can be manufactured only for passports or for cheques with signature verification.

Biometrics includes wide range of research areas; fingerprint, face, iris, hand palm, handwritten recognition. The device can be modified to be used for the multi biometric applications. The new cameras and a fingerprint sensor can be mounted on the available device with extension of other types of biometric data. The identification of the human can be performed with inclusion of multi biometric data. Further study can involve the investigation of other methods in addition to the one applied.

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