REPORT

A. "SALAMI SLICING" – "DUPLICATION" in 4 articles :

Article-1.
Necla Özkaya, Şeref Sağıroğlu,
"Parmakizinden yüz tanıma",
Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, cilt.23, no.4, 2008, 785-793
(Geliş/Received: 12.11.2007 ;
Kabul/Accepted: 22.09.2008)

Article-2.
Şeref Sağıroğlu, Necla Özkaya,
"An intelligent face feature generation system from fingerprints",
TÜBİTAK Elektrik, vol.17, no.2, 2009, 183-203

Article-3.
Necla Ozkaya, Seref Sagiroglu
Generating One Biometric Feature from Another: Faces from Fingerprints
Sensors 2010, 10, 4206-4237; doi:10.3390/s100504206
(Received: 20 January 2010; in revised form: 4 March 2010 /
Accepted: 22 March 2010 /
Published: 28 April 2010)

Article-4.
Seref Sagiroglu, Necla Ozkaya
An Intelligent and Automatic Face Shape Prediction System From Fingerprints
Intelligent Automation and Soft Computing, Vol. 17, No. 3, pp. 309-317, 2011

Thesis-NO.
Necla Özkaya,
Esnek Hesaplama Yöntemleri ile Parmakizi Yüz Biyometrik Özelliklerinin İlişkilendirilmesi,
(= Investigating Relationships Between Fingerprint and Face Biometrics by Soft Computing Based Methods)
June 2009, 345 pgs, phd thesis, in Turkish, Erciyes University, Computer Engineering
supervisor : Şeref Sağıroğlu
jury : Kenan Danışman, Derviş Karaboğa, Erdoğan Doğdu, Erkan Beşdok

A.1. Abstract :

Article-1 :
....
A **new** and **novel approach based on artificial neural networks was designed and introduced to generate faces from fingerprint images.**
Experimental results have shown that faces were recognised **with high accuracy** from only fingerprints.
Although the proposed system was an initial work on this topic, the results were very encouraging and promising for the future studies even if any post-processing was not applied.

Article-2 :
In this study, a **novel** intelligent system **based on artificial neural networks was designed and introduced for generating faces from fingerprints with high accuracy.**
The proposed system has a number of modules including
two feature enrolment modules for acquiring the fingerprints and faces into the system,
two feature extractors for extracting the feature sets of fingerprint and face biometrics,
an artificial neural network module
that was configured with the help of Taguchi experimental design method
for establishing relationships among the biometric features,
a face re-constructor for building up face features from the results of the system, and
a test module for test the results of the system.
10-fold cross validation technique was used for evaluating the performance of the system.
The results have shown that the face features can be successfully generated from only fingerprints.
....

Article-3 :
This study presents a **new approach based on artificial neural networks for generating** one biometric feature (**faces**) **from** another (**only fingerprints**).
....
The new proposed system is the first study that generates all parts of the face including
eyebrows, eyes, nose, mouth, ears and face border from only fingerprints.
It is also unique and different from similar studies recently presented in the literature with some superior features.
The parameter settings of the system were achieved with the help of Taguchi experimental design technique.
The performance and accuracy of the system have been evaluated with 10-fold cross validation technique using qualitative evaluation metrics
in addition to the expanded quantitative evaluation metrics.
....
Experimental results have shown that one biometric feature can be determined from another.
These results have once more indicated that there is a strong relationship between fingerprints and faces.

Article-4 :
This paper presents **an intelligent system for generating face shapes from only fingerprints** without knowing any information about faces.

The proposed system based on artificial neural network has got a number of modules including
two biometric data acquisition modules,
two feature extraction modules,
an artificial neural network module,
a face re-construction module and
a test & evaluation module.
Experimental results have shown that the faces can be successfully generated from only fingerprints.
Although the proposed system is an initial study, the performance of the system is very promising for the future developments.

Thesis-NO :
....
This thesis presents a **new approach for generating faces from only fingerprints based on artificial neural networks.**
....
Proposed system is unique and different from the other studies in the biometrics field being the first study that investigates the relationships among biometric features and generates face of an individual from only one fingerprint of the same individual without any information about his or her face.
The proposed system has a complex structure with five main components:
two biometric feature enrolment modules,
two feature extraction modules,
a main body based on artificial neural network,
a face re-construction module and
an test & evaluation module.
Two biometric feature enrolment modules are used for acquiring the fingerprints and faces of the people to the system.
Two feature extraction modules are used for extracting the feature sets of fingerprint and face biometrics.
The artificial neural network based main body
that was configured with the help of Taguchi experimental design method is responsible for establishing relationships among the biometric features of fingerprints and faces.
The face re-construction module is utilized for building up face features from the results of the system.
Finally the test & evaluation module is responsible for test and evaluating the results of the system properly.
The system results have shown that the face features can be successfully generated from only fingerprints.
For a more objective comparison, the performance and accuracy of the system have been evaluated with 10-fold cross validation technique
using qualitative evaluation metrics
in addition to the quantitative evaluation metrics.
....
Experimental results have shown that there are close relationships among the features of fingerprints and faces.
It is also possible to generate faces from just fingerprints without knowing any information about faces.
....

A.2. Experiment which is told in article :

Article-1 : (in Turkish)

(pg 788, left column, paragraph 2, last 2 lines)
(see : Sunulan çalışmada, **parmakizinden yüzü tanıyan** zeki **bir sistem gerçekleştirilmiştir**.)
experiment : implementation of a system which recognizes face from fingerprint

(pg 788, right column, paragraph 2, last 3 lines)
(see : Kişinin **sağ el işaret parmağı** ile **kaşlar, gözler, burun** ve **ağız** olarak sıralanabilen **yüze ait temel bileşenler** arasındaki ilişkiler dikkate alınmıştır.)
fingerprint used in experiment : right index finger

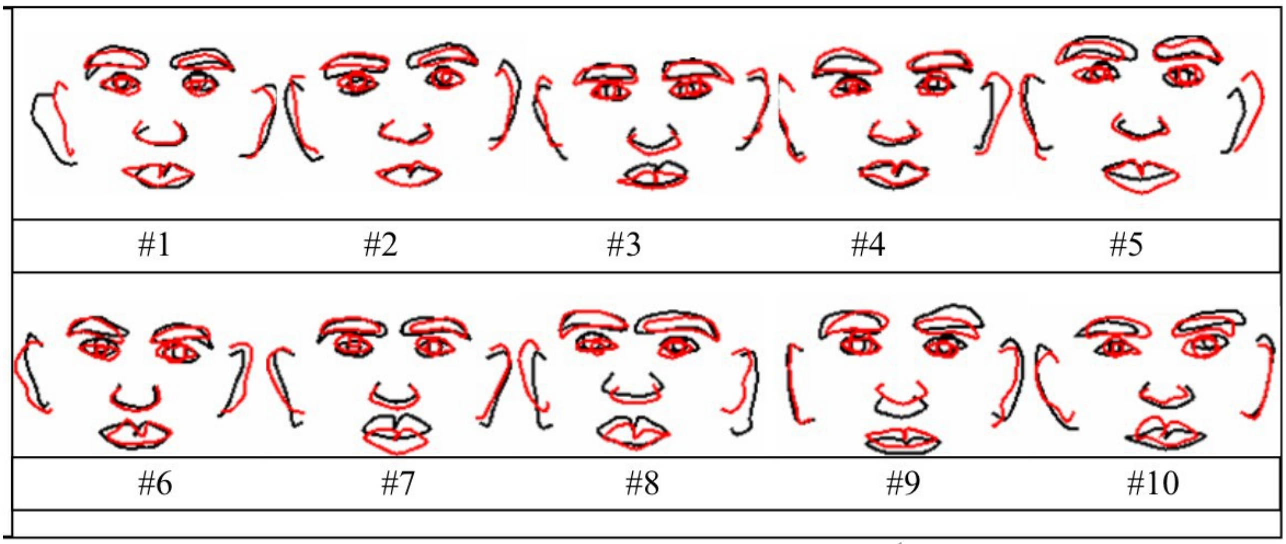
(see : Şekil-3.b, Şekil-4, Şekil-5)
face components used in experiment : eyebrows, eyes, nose, mouth, ears

(see : Şekil-2)
no of points on face template : 88

(see : pg 789, left column, last paragraph)
no of inputs of neural network : 298 (should be = (x, y) coordinates of 149 points)
no of outputs of neural network : 132 (should be = (x, y) coordinates of 66 points)

(pg : 788, paragraph 3)
no of owners of fingerprints and faces used in experiment : 120
no of owners of fingerprints and faces used in experiment to train neural network : 80
no of owners of fingerprints and faces used in experiment to test neural network : 40

Şekil-4 : face components used in experiment : eyebrows, eyes, nose, mouth, ears



Article-2 :

(pg 190, paragraph 1, line 4)
(see : Developed ANN based intelligent system generates the inner face features including **eyes, nose** and **mouth** of an individual from only one fingerprint of the same individual.)
experiment : implementation of a system which generates face from fingerprint

(pg 190, paragraph 1, last 2 lines)
(see : Only a frontal face image and index finger of the right hand were taken into consideration in this study.)
fingerprint used in experiment : right index finger

(see : Figure-8.a..j)
face components used in experiment : eyes, nose, mouth

no of points on face template : ??

(see : pg 193, paragraph 2, last 4 lines)
(The sizes of the input and the output vectors were also 300 and 76, respectively. The size of input (the feature sets of fingerprints) is fixed to 300 because of their different lengths. If the size of input is larger than 300 it is fixed to 300. If the size of inputs is smaller than 300, zeros are added to the string to complete it to 300.)
no of inputs of neural network : 300 (should be = (x, y) coordinates of 150 points)
no of outputs of neural network : 76 (should be = (x, y) coordinates of 38 points)

(see : pg 190, paragraph 1, line 3rd from end)
no of owners of fingerprints and faces used in experiment : 120
no of owners of fingerprints and faces used in experiment to train neural network : 120 (?)
no of owners of fingerprints and faces used in experiment to test neural network : 120 (?)

Figure-8.a : face components used in experiment : eyes, nose, mouth

Article-3 :

(see : pg 4221, paragraph 2, line 4)
(.... a proposed **system** .... was developed and implemented. The new approach successfully **generates total face features containing all of the face parts including eyebrows, eyes, nose, mouth and face contours including face border and ears from only fingerprints** without having any information about faces in this study.)
experiment : implementation of a system which generates face from fingerprint

(see : pg 4225, paragraph 2, last 2 lines)
(Only a frontal face image and index finger of the right hand were taken into consideration in this study.)
fingerprint used in experiment : right index finger

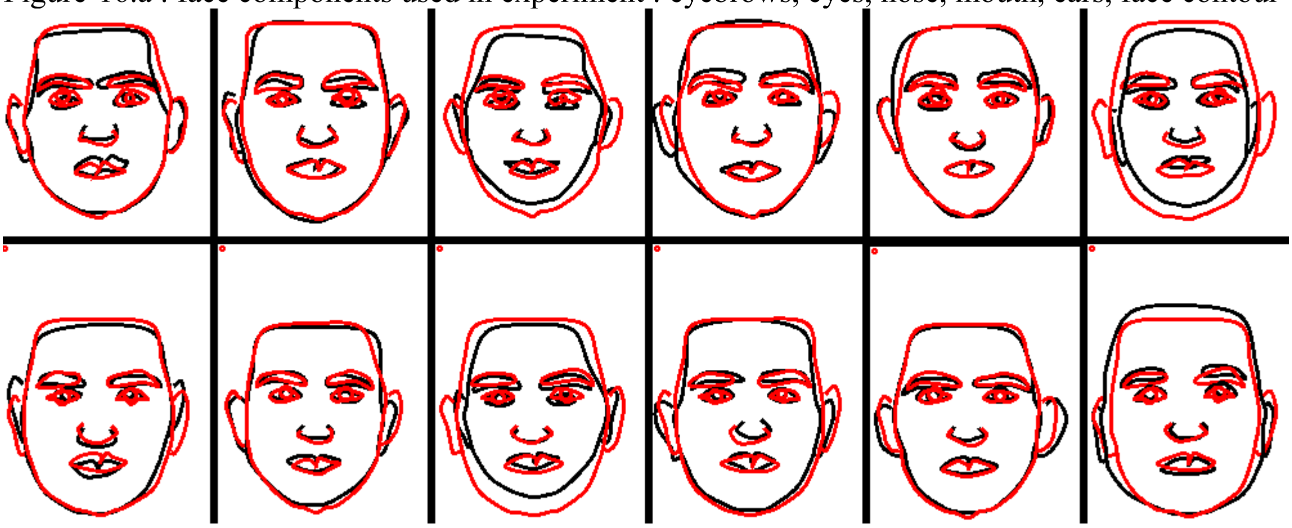
(see : Figure-4, 10, 16.a..j)
face components used in experiment : eyebrows, eyes, nose, mouth, ears, face contour

(see : Figure-10)
no of points on face template : 88

(see : pg 4221, paragraph 7, line 1) : (.... the numbers of inputs were 200 and 300.)
(see : pg 4222, paragraph 1, line 3-4) : (The sizes of input and output vectors were also 300 and 176, respectively.)
no of inputs of neural network : 200 (should be = (x, y) coordinates of 150 points) and
300 (should be = (x, y) coordinates of 150 points)
no of outputs of neural network : 176 (should be = (x, y) coordinates of 88 points)

(see pg 4221, paragraph 1, line 1)
no of owners of fingerprints and faces used in experiment : 120
no of owners of fingerprints and faces used in experiment to train neural network : 120 (?)
no of owners of fingerprints and faces used in experiment to test neural network : 120 (?)

Figure-16.a : face components used in experiment : eyebrows, eyes, nose, mouth, ears, face contour



Article-4 :

(see : pg 311, paragraph 1)
(Unlike to the previous studies [2]-[10], the proposed ANN based intelligent s**ystem generates the face shape including eyes, mouth and face border of a person from only one fingerprint of the same person.**)
experiment : implementation of a system which generates face from fingerprint

(see : pg 311, paragraph 2, line 3-4)
(Only a frontal face image and a fingerprint that was index finger of the right hand were used in this study.)
fingerprint used in experiment : right index finger

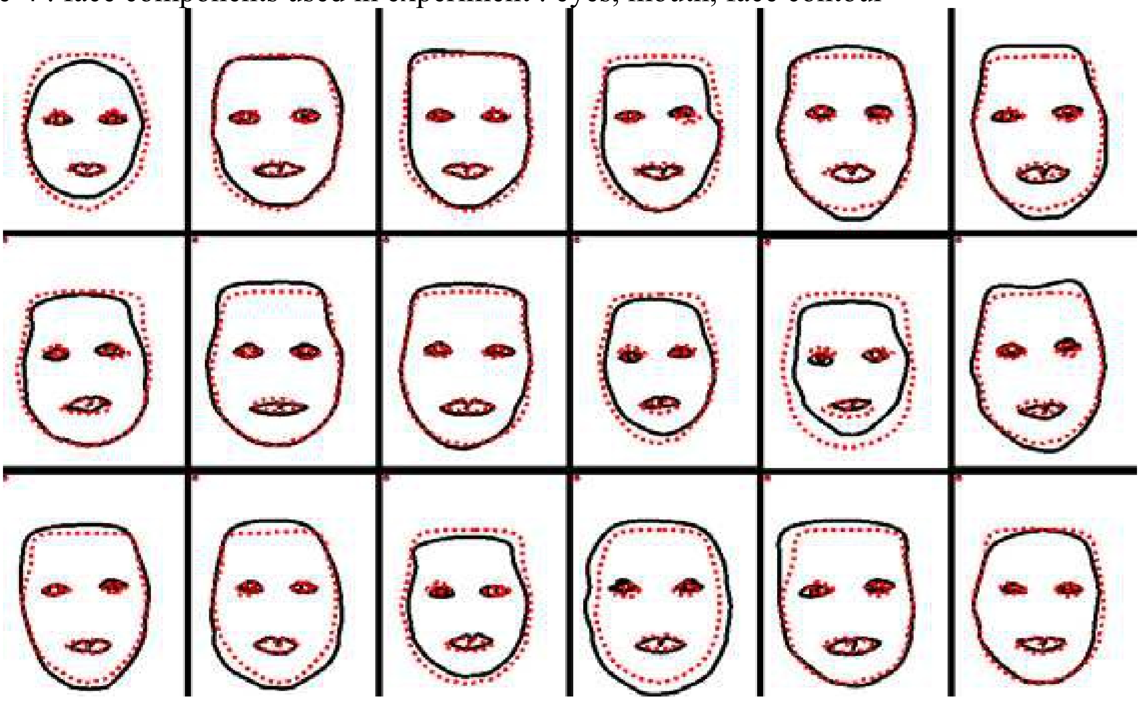
(see : Figure-4)
face components used in experiment : eyes, mouth, face contour

no of points on face template : ??

(see : pg 312, last paragraph, line 4th from end)
no of inputs of neural network : 298 (should be = (x, y) coordinates of 149 points) and
no of outputs of neural network : 106 (should be = (x, y) coordinates of 53 points)

(see : pg 311, paragraph 2, line 2)
no of owners of fingerprints and faces used in experiment : 120
(see : Figure-5.a, b)
no of owners of fingerprints and faces used in experiment to train neural network : 80
no of owners of fingerprints and faces used in experiment to test neural network : 40

Figure-4 : face components used in experiment : eyes, mouth, face contour



Thesis-NO : (in Turkish)

(see : pg 130, paragraph 2)
(Sunulan çalışmada, **parmak izinden yüzü elde etmeye yönelik olarak gerçekleştirilen sistem**in yüksek doğruluklu sonuçlara ulaşması hedeflenmektedir.)
(see : pg 130, paragraph 1, line 2-3)
(.... **parmak izinden yüzü tahmin edebilen** otomatik ve zeki **bir sistem geliştirilmiştir.**)
experiment : implementation of a system which generates face from fingerprint

(see : pg 307, no 12)
(12. Çalışma ilk aşamada OPTOS'larda en çok tercih edilen parmak izi olan s**ağ el işaret parmağı**na ait parmak izleri kullanılarak gerçekleştirilmiştir.)
fingerprint used in experiment : right index finger

(see : Şekil-4.22.a..c)
face components used in experiment : eyebrows, eyes, nose, mouth, ears
(see : Şekil-6.6)
eyes
(see : Şekil-6.12)
nose
(see : Şekil-6.18)
mouth
(see : Şekil-6.24)
face contour
(see : Şekil-6.30)
eyebrows
(see : Şekil-6.36)
ears
(see : Şekil-7.6)
eyes, nose
(see : Şekil-7.12)
ears, face contour
(see : Şekil-7.18)
eyebrows, eyes, nose
(see : Şekil-7.24, Şekil-4.17)
eyes, nose, mouth
(see : Şekil-7.30)
eyebrows, eyes, nose, mouth
(see : Şekil-7.36)
eyes, nose, mouth, face contour
(see : Şekil-7.42, 5.24..28)
eyebrows, eyes, nose, mouth, face contour
(see : Şekil-7.48)
eyebrows, eyes, nose, mouth, ears, face contour

(see : Şekil-5.8, 14)
no of points on face template : 88

(see : pg 289, paragraph 1) : (.... 300 girişli 176 çıkışlı bir FF YSA yapısı kullanılmıştır.)
(for fingerprint --> eyebrows, eyes, nose, mouth, ears, face contour)
no of inputs of neural network : 300 (should be = (x, y) coordinates of 150 points)
no of outputs of neural network : 176 (should be = (x, y) coordinates of 88 points)
(see : pg 282, paragraph 1, last 2 lines) : (.... 300 girişli 148 çıkışlı bir FF YSA yapısı kullanılarak elde edilen sonuçlar)
(for fingerprint --> eyebrows, eyes, nose, mouth, ears, face contour)
300
148

(for fingerprint --> eyes, nose, mouth, face contour)
?? , ??
(see : pg 268, paragraph 1) : (.... 300 girişli 104 çıkışlı bir yapı kullanılmış ....)
(for fingerprint --> eyebrows, eyes, nose, mouth)
300
104
(see : pg 261, paragraph 1, line 2) : (.... 300 girişli 76 çıkışlı bir FF YSA yapısı kullanılmıştır.)
(for fingerprint --> eyes, nose, mouth)
300
76

(for fingerprint --> eyebrows, eyes, nose)
?? , ??
(see : pg 261, paragraph 1, line 2) : (.... 300 girişli 72 çıkışlı bir FF YSA yapısı kullanılmıştır.)
(for fingerprint --> ears, face contour)
300
72

(for fingerprint --> eyes, nose)
?? , ??

(for fingerprint --> eyebrows) : ?? , ??
(for fingerprint --> eyes) : ?? , ??
(for fingerprint --> nose) : ?? , ??
(for fingerprint --> mouth) : ?? , ??
(for fingerprint --> ears) : ?? , ??
(for fingerprint --> face contour) : ?? , ??

(see pg 153, paragraph 1, line 1)
no of owners of fingerprints and faces used in experiment : 120
no of owners of fingerprints and faces used in experiment to train neural network : 120
no of owners of fingerprints and faces used in experiment to test neural network : 120

A.3. Turnitin Reports :

Article-1 :

Article-2 :
Similarity Ratio : 53 %
28 % of it = Article-3 (similarity of text ; figures are NOT included)

Figure-2.a..d of it = Figure-6.a..d of Article-3
Figure-3.a..c of it = Figure-7.a..c of Article-3
Figure-4.a..d of it = Figure-8.a..d of Article-3
--> these figures occupy 2 full pages

Table-1 of it = Table-4 of Article-3
Table-2 of it = Table-5 of Article-3

Article-3 :
Similarity Ratio : 42 %
22 % of it = Article-2 (similarity of text ; figures are NOT included)

Figure-2.a..d of Article-2 = Figure-6.a..d of it
Figure-3.a..c of Article-2 = Figure-7.a..c of it
Figure-4.a..d of Article-2 = Figure-8.a..d of it
--> these figures occupy approximately 2 full pages

Table-1 of Article-2 = Table-4 of it
Table-2 of Article-2 = Table-5 of it

Article-4 :
Similarity Ratio : 56 %
30 % of it = Article-2 (similarity of text ; figures are NOT included)
9 % of it = Article-3 (similarity of text ; figures are NOT included)

B. “IRREPRODUCIBLE Results” in 4 articles :

Thesis-NO :

(see pg 300, paragraph 1, last 2 lines) : Aksine l**iteratürde parmak izi ve yüzün birbirinden bağımsız veriler olduğu kabulü yaygındır** [7].

On the contrary (to the results of this thesis), **it is commonly accepted in the literature that fingerprint and face are independent variables.**

Theoretically Impossible – 1 :
Input of neural network n x 2 vector ; (x, y) coordinates of n points
Output of neural network m x 2 vector ; (x, y) coordinates of m points
In all articles, input and output are assument as scalar, NOT as n x 2 vector.

Theoretically Impossible – 2 :
Dataset obtained from 120 samples are NOT enough for input and output sizes of all articles (298 and 132 ; 300 and 76 ; 200 or 300 and 176 ; 298 and 106).

Hand-drawn face figures which are given as results :
See “curves” at face figures. “Curve formulas” are required to draw curves with a software. There is no information that if any “curve formula” is used to draw face figures.

B.1. Request to Repeat the experiment
These articles is the unique source of the experiment which is told in them.
This experiment requires to be repeated by academics to see if it can reproduce the same results.

To prevent any objection, unique way to repeat this experiment is to use original data and software code, if there is (!).
Simplest experimental setup requires only these :
- compilable source code of neural network part of software, if there is (!), which reads calculated and saved “weight” values of neural nework from a file, which reads fingerprint data, and which outputs and save face data
- “weight” values file
- 1 fingerprint data file in txt format
- compilable source code of face parts drawing part of software, if there is (!), which reads face data and outputs face parts image
- hints to compile these 2 software codes
- supplementary files to compile and run these 2 software codes

If there is any “neural network” software code, it can be seen in it that if it produces face figures data really by using neural network calculations or not.
If there is any “face parts drawing” software code, it can be seen in it that if it draws face figures or not.

Gazi Üniv. Müh. Mim. Fak. Der. J. Fac. Eng. Arch. Gazi Univ.
Cilt 23, No 4, 785-793, 2008 Vol 23, No 4, 785-793, 2008

PARMAKİZİNDEN YÜZ TANIMA

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ÖZET

Literatürde biyometrik tanıma sistemlerine yönelik birçok başarılı teknik, yaklaşım ve algoritma geliştirilmiş ve gerçekleştirilmiştir. Bu çalışmalar incelendiğinde biyometrik özellikler arasındaki ilişkinin analizine yönelik herhangi bir çalışmaya rastlanmamaktadır. Sunulan çalışmada parmakizi, yüz, iris, retina ve el geometrisi gibi biyometrik özellikler arasında olabilecek herhangi bir ilişkinin varlığı tartışılmakta ve kişilerin yalnızca parmakizini kullanarak yüzlerini tahmin etmeye yönelik yapay sinir ağları temelli yeni ve zeki bir sistem tanıtılmaktadır. Elde edilen sonuçlar, sunulan çalışmanın bu konuda gerçekleştirilmiş bir ilk çalışma olmasına ve sonuçların hiç bir son işlemden geçirilmeden en ham şekliyle sunulmasına rağmen başarısının kabul edilebilir niteliklerde olduğunu ve gelecekte konuyla ilgili farklı çalışmaların geliştirilmesine katkı sağlayacağını göstermektedir.

Anahtar Kelimeler: Biyometrik teknikler, parmakizi tanıma, yüz tanıma, yapay sinir ağları, akıllı biyometrik sistemler.

FACE RECOGNITION FROM FINGERPRINTS

ABSTRACT

As many approaches and algorithms for biometric recognition techniques have been developed and proposed in the literature in details, the relationships among biometric features have not been studied yet. This study presents an analysis of existence of any relationship among biometric features like fingerprints and faces. A new and novel approach based on artificial neural networks was designed and introduced to generate faces from fingerprint images. Experimental results have shown that faces were recognised with high accuracy from only fingerprints. Although the proposed system was an initial work on this topic, the results were very encouraging and promising for the future studies even if any post-processing was not applied.

Keywords: Biometric technics, fingerprint verification, face recognition, artificial neural network, intelligent biometric systems.

1. GİRİŞ (INTRODUCTION)

Kişilerin fiziksel veya davranışsal özelliklerin kullanılarak tanınması/onaylanması olarak açıklanabilen biyometri bilimi, parmakizi, yüz, kulak, iris, retina, el geometrisi, ses gibi kişiyi fizyolojik veya davranışsal bir özelliğiyle temsil edebilecek kadar kişiye özgü, kişiden kişiye kolayca aktarılamayacak kadar güvenilir, hayatın başlangıcından sonuna kadar değişmeyen kalıcı özellikleri kapsar [1]. İlk zamanlarda yüksek güvenlik gereken ve bireyin kimliğinin doğru tespit edilmesinin çok önemli olduğu alanlarda kullanım alanı bulan biyometri günümüzde sıkça karşımıza çıkan bir teknoloji haline gelmiştir [2]. Biyometrinin günümüzde turizm sektöründe, giriş-çıkış kapılarında kimlik tespiti ve benzer güvenlik fonksiyonlarında, bilgisayar ve bilgisayar ağlarında erişim düzeninin sağlanmasında ve kaynakların paylaşımında, ağ güvenliğinin sağlanmasında, fiziksel giriş çıkış kontrol noktalarında, personel devam kontrol sistemlerinde, ticari işlemler ve benzer birçok alanda, banka güvenliğinde elektronik fon transferi veya ATM güvenliği gibi işlemlerde, çek ve kredi kartı işlemlerinde, gümrük ve göç işlemlerinde daha güvenli ve hızlı işlem için, ulusal kimliklendirme sistemlerinde daha güvenilir ve düzenli kimliklendirme için, seçmen ve sürücü kayıtlarında, internet işlemlerinde verimli bir şekilde uygulandığı ve insan hayatında geniş yelpazede çözümler sunan bir teknoloji olduğu görülmektedir [2,3]. Son yirmi yıl içerisinde biyometrik tanıma sistemleri konusu bir çok açıdan incelenmiş, konunun değişik yönlerine ve detaylarına yönelik çeşitli teknikler, verimli algoritmalar ve yöntemler kullanılarak konuyla ilgili birçok problem için çeşitli çözümler ortaya konulmuştur [2-7]. İlk zamanlar çalışmalar biyometrik sistemlerde doğruluğun ve güvenilirliğin arttırılmasına, sistemin işleyişine ve iyileştirilmesine yönelik olmakla birlikte son yıllarda araştırmacıların ilgisi biyometrik tekniklerin birleştirilerek kullanıldığı, doğruluk ve güvenliği bir üst seviyeye çıkaran çoklu biyometrik sistemler üzerine yoğunlaşmıştır [3,6-12]. Tüm bu ilgi ve gelişmelere rağmen literatürde biyometrik özellikler arasında olabilecek herhangi bir ilişki üzerine bir çalışma yapılmamıştır. Yazarların son aylarda kabul edilen çalışmalarında, parmakizi ile yüz arasında bir ilişki olduğu rapor edilmiştir [27-32]. Bu çalışmalarda; parmakizinden yüz çerçevesi [27], yüz çerçevesi ve kulak [28], kaş, göz ve ağız [29], kaş, göz, ağız, kulak [30], göz, burun, kulak ve yüz sınırları [31] ve göz, burun, kulak, ağız ve yüz çevresi [32] elde edilmiştir. Bu çalışmada ise parmakizinden göz, kulak ve kaş bilgisi elde edilebilmektedir.

Parmakizi ile yüz arasındaki olabilecek ilişkinin analizi ve incelenmesi konusunda en önemli öncelik gerçek bir çoklu biyometrik özellikler veritabanı (ÇBVT) oluşturulmasıdır. Bu nedenle çalışmaya aynı kişilere ait parmakizi ve yüz biyometrik özelliklerini içeren bir ÇBVT oluşturularak başlanmıştır. Böyle bir veritabanının hali hazırda insanların erişebileceği veya kullanabileceği bir platformda olmayışı çalışmaya buradan başlamayı zorunlu kılmıştır [17]. Bu yüzden genellikle çoklu biyometrik özelliklerle çalışan bilim adamları; [12] nolu çalışmada olduğu gibi kendi ÇBVT'lerini kendi imkanları dahilinde oluşturmakta, bunun sonucu olarak da literatürde bulunan ÇBVT'ler tüm insanların kullanabilecekleri platformlarda bulunamamaktadır. Ayrıca herkesin kendi çabasıyla oluşturulan veritabanları hem uluslararası standartlarda olmamakta hem de ufak boyutlu oldukları için sonuçların değerlendirilmesinde yetersiz kalmaktadır [17].

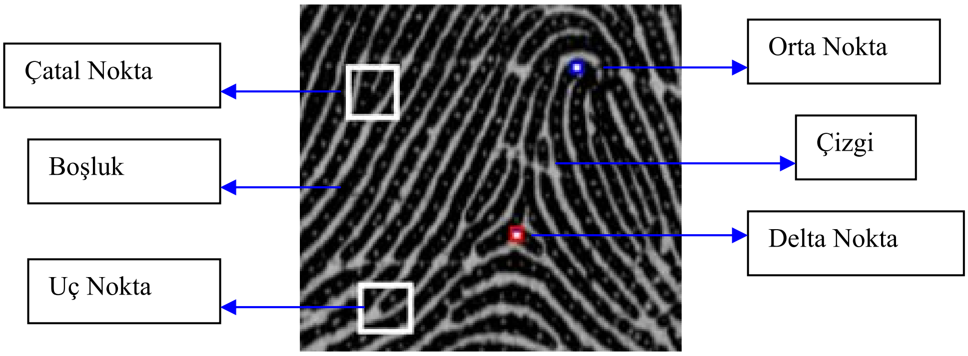
Sunulan çalışmada, parmakizi ile yüz biyometrik özellikleri arasında olabilecek bir ilişkinin varlığı araştırılmış ve bu özellikler arasında geçiş yapabilecek yeni ve zeki bir sistem tasarlanmıştır. Sözü edilen zeki sistem bu çalışmada tanıtılmıştır. Literatürde hiç araştırılmamış ve çalışılmamış bir konuda başarılı sonuçlar alınması, sunulan bu sistemin biyometrik özellikler arasındaki olabilecek ilişkilerin tespiti ve analizine yönelik gelecekte yapılacak pek çok çalışma ve uygulamanın önünü açacak önemli bir çalışma olarak değerlendirilmektedir.

2. BİYOMETRİK SİSTEMLERE GENEL BAKIŞ (OVERVIEW OF BIOMETRY SYSTEMS)

Bir biyometrik sistem en genel anlamda bireyin biyometrik özelliğini alan, bu özellikten kişinin kimliklendirilmesinde kullanılacak olan özellik setini çıkaran ve kişiyi temsil eden bu anlamlı veri seti ile daha önceden aynı prensiplerle elde edilip veritabanına kaydedilmiş veri seti/setleri arasında karşılaştırma yapan bir tanıma/onaylama veya sınıflandırma sistemi olarak tarif edilebilmektedir [13]. Biyometrik sistemler çalışma şekli ve uygulama durumuna göre 4 gruba ayrılırlar. Bunlar kayıt modu (enrollment), onaylama modu (verification), tanıma modu (identification) ve izleme modu (screening) şeklinde sıralanmaktadır [1]. Temelde hepsinin çalışma prensibi aynı olmakla birlikte modlar uygulama şekli ve kullanım alanı konusunda bazı farklılıklara sahiptirler. Örneğin kayıt modu biyometrik verinin sisteme alınması, sınıflandırılması ve kaydedilmesi işlemlerini kapsamaktadır. Onaylama modu "kullanıcı adı + biyometrik veri" kombinasyonunu sisteme giriş olarak alıp birebir karşılaştırma (1-1) sonucu sistem cevabını oluşturmak şeklinde tanımlanmakta ve genelde personel takibi gibi giriş-çıkış kontrol noktalarında tercih edilmektedir. Tanıma modu yalnızca biyometrik veriyi sisteme giriş olarak alıp veritabanındaki tüm kayıtlarla tek tek karşılaştırma (1-n) yaparak sistem cevabını oluşturmakta ve genelde suç ve suçlu takibi gibi işlerde kullanılmaktadır. İzleme modu ise herhangi bir kişinin arananlar listesinde olup olmadığının araştırılmasında görev yapmaktadır. Havaalanı güvenliği, herkesin kullandığı kamuya ait alanların güvenliği ve diğer takip ve gözlem gerektiren uygulamalarda tercih edilmektedir.

Bir otomatik parmakizi tanıma ve onaylama sistemi (OPTOS) parmakizi resminde bulunan çizgilerdeki özellikler ve bu özelliklerin parametrelerinin benzerliklerini ve farklarını kullanarak kimliklendirme yapmaktadır [9,14]. Kimliklendirme işleminde kullanılan ve yerel özellikler olarak bilinen parmakizi çizgilerindeki ani sonlanmalar veya ikiye ayrılışlar olarak tarif edilebilen uç ve çatal noktalar ve bu noktaların temsilinde kullanılan global özellikler olarak bilinen orta nokta ve delta noktaları Şekil 1'de verilmektedir.

Özellik noktalarının karşılaştırılması temelli OPTOS'lar genellikle üzerinde işlem yapılacak resim alanının seçilmesi, referans noktaların belirlenmesi, resmin temizlenip iyileştirilmesi, inceltilmesi, özellik setinin elde edilmesi ve gerçek özellik setinin oluşturularak parmakizinin özellik seti ile en iyi şekilde temsil edilmesi, özellik setinin veritabanında kayıtlı özellik seti/setleriyle karşılaştırılması işleminin



Şekil 1. Parmakizi yapısı ve parmakizine ait yerel ve global özellikler (Ridge-valley structure and local and global features of fingerprints)

yapılması, sistemin test edilmesi ve test sonuçlarının değerlendirilmesi işlemlerinden oluşmaktadır [15].

Bir otomatik yüz tanıma ve onaylama sistemi kişilerin durağan resimleri veya video görüntüleri üzerinden ilgili kişilerin veritabanına kayıtlı resimlerinin kullanılarak kimliklendirilmesi şeklinde tanımlana-bilir. Yüz tanıma işlemi kişinin yüzüne ait özelliklerin değişmesine neden olan yüz ifadelerindeki değişiklikler, 3 boyutlu poz farklılıkları, makyaj, yüzün bir kısmını veya tamamını kapatan aksesuarlar, saç şekli ve benzeri birçok faktör olması nedeniyle oldukça karmaşık ve zor bir iştir [16]. Bir yüz tanıma sistemi karmaşık bir arka plandan yüzlerin ayırt edilmesi, yüze ait özellikler ve bu özellikler yardımıyla yüz yeri ve yönünün belirlenmesi ve tanıma/onaylama işleminin gerçekleştirilmesi olmak üzere temelde üç adımdan oluşmaktadır [16]. Yüz tanıma ile ilgili literatür incelendiğinde yüz tanıma ile ilgili yöntemlerin temelde 4 ana grupta toplandığı görülmektedir [6]. Bu yöntemler ana hatlarıyla aşağıda tanıtılmaktadır.

I. **Bilgi temelli metotlar:** Kural tabanlı metotlar olarak ta bilinirler. Genellikle yüz yerinin tespiti ve yüze ait özellik setinin elde edilmesinde kullanılmak üzere tasarlanmış olan bu metotlar tipik bir yüzün insan beyninde nasıl şifrelendiği düşünülerek geliştirilmiştir.
II. **Değişmeyen özelliklere dayalı yaklaşımlar:** Bu algoritmalar yüzde var olan ve poz, bakış açısı, çeşitli aydınlatma koşullarına rağmen değişmeyen sabit kalan özellikleri bulma ve bunları kullanarak yüz yerinin tespiti ve yüz tanıma işleminin gerçekleştirilmesi için geliştirilen yöntemlerdir. Yüze ait özellikler, doku analizi, ten rengi veya birden fazla özellik kullanılarak işlem yapılan çalışmalar bu gruba girmektedir.
III. **Şablon karşılaştırmaya dayalı metotlar:** Bir yüze veya yüzün parçalarına ait çeşitli standart şablonlardan çok sayıda depolayıp karşılaştırma mantığına dayanan bir yöntemdir. Giriş resmiyle önceden tanımlanmış veya şekil değiştirebilen kayıtlı şablonlar arasındaki benzerlik oranına bakılarak yüz yeri tespit edilmeye ve yüz tanıma yapılmaya çalışılır.
IV. **Görünüş temelli metotlar:** Bu yöntemlerde şablon karşılaştırmanın tersine, modeller veya şablonlar bir veri setinden öğrenilir. İlgili veri seti yüzün çeşitli şekillerinde, çeşitli şartlarda ve çeşitli pozisyonlarda alınan resimlerinden oluşan eğitim setidir. Bu öğrenilen modeller daha sonra yüz tanıma işlemi için kullanılmaktadır. Öz yüz yöntemi ve öz yüzün iyileştirilmiş versiyonları (doğrusal diskriminant analizi, ayırt edici ortak vektör yöntemi vs), dağılım tabanlı yöntemler, yapay sinir ağları, karar destek mekanizmaları, gizli markov modelleri gibi çeşitli yöntemler kullanılarak işlemler gerçekleştirilmektedir.

Son yıllarda kişilerin kimliklendirilmesi için biyometrik özelliklerin birleştirilerek kullanıldığı çalışmalar revaçtadır [3,10,11,13,33]. Biyometrik özeliklerin birleştirilmesi, sistemin bozucu etkilere karşı daha güçlü olmasını, doğruluğunun ve güvenilirliğinin artmasını sağlamakta ve kullanıcılara biyometrik sistemler bünyesindeki dezavantajları en aza indirgeyerek avantajları kullanma imkanı sunmaktadır. Tekli biyometrik sistemlere göre daha iyi performans, hız ve doğruluk sağlıyor olması bu konuda çalışan teknoloji üreticilerinin, algoritma geliştiricilerin ve bilim adamlarının dikkatini bu yöne yöneltmiştir [3]. Çoklu biyometrik sistemlerin avantajları literatürde sıkça belirtilmektedir. Prabhakar ve Jain çalışmalarında birden fazla sensor (optic ve kapasitif), biyometrik özellik (parmak izi yüz), biyometrik birim (sağ el işaret parmağı ve sağ el orta parmak), karşılaştırma mekanizması (özellik noktaları temelli, yönelim haritası temelli) ve aynı biyometrik özelliğin farklı şekillerde alınması (sağ el işaret parmağının değişik şekillerde alınması) şeklinde oluşturulan çoklu biyometrik sistemlerin doğruluğu-nun ve başarısının normal biyometrik sistemlere göre daha iyi olduğunu belirtmektedirler [13]. [33] nolu kaynakta Jain ve arkadaşları çoklu biyometrik sistemler hakkında detaylı olarak verdikleri temel bilgilerin yanı sıra konuyu değişik açılardan yorumlamışlardır.

Çoklu biyometrik sistemler incelendiğinde iki biyometrik özellik karar seviyesi, benzeşme oranları seviyesi ve özellik çıkarım seviyesi olmak üzere temelde 3 seviyede birleştirilmektedir [10], [11]. Özellik çıkarım seviyesindeki birleştirmede her iki biyometrik özelliğin özellik seti farklı farklı elde edilip bu özellik setleri birleştirilmektedir. Benzeşme oranları seviyesindeki çoklu sistemde biyometrik özelliklerin ayrı ayrı özellik seti çıkarılıp benzeşme oranları hesaplanmakta ve bu aşamada birleştirme işlemi gerçekleştirilmektedir. Karar seviyesinde ise her iki biyometrik özellik birbirinden bağımsız olarak işlemlere tabi tutulmakta sonuçta bir karar vermekte ve sonra bu kararlar birleştirilerek sistem sonucu oluşturulmaktadır [13].

3. PARMAKİZİNDEN YÜZÜ TANIYAN ZEKİ SİSTEM (PYTZS) (INTELLIGENT SYSTEM GENERATING FACES FROM FINGERPRINTS)

Kişinin tanınmasında ve kimliklendirilmesinde uzun zamandır kullanılan ve "kişiye özgü" kavramıyla özdeşleşen biyometrik özellikler kullanılarak kişileri yüksek doğruluklarla tanıyıp kimliklendirebilmek mümkün olmaktadır. Yapılan pek çok çalışmada, nano mertebesinde olan özelliklerde kişiye has özelliklerin bulunması veya genetik olarak saklanması fikri, bizde de biometrik özellikler arası bir geçiş olabileceği fikrini oluşması fikrini doğurmuştur. Sunulan çalışmada, parmakizinden yüzü tanıyan zeki bir sistem gerçekleştirilmiştir.

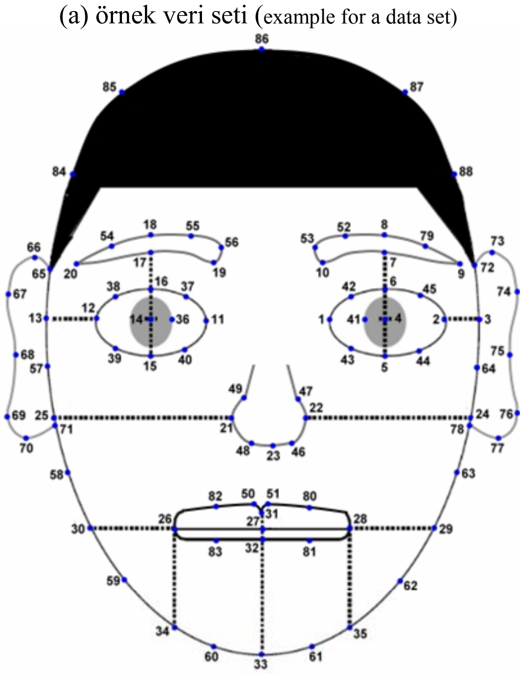
Geliştirilen bu zeki sistem, 120 kişinin parmakizi ve yüz resimlerinden oluşan bir çoklu biyometrik özellikler veritabanı (ÇBVT) kullanılarak oluşturulmuştur. Bu resim çiftleri gerektiği şekilde işlenerek parmakizlerine ve yüzlere ait özellik setleri elde edilmiştir. Parmakizi ve yüze ait özellik setleri arasında herhangi bir ilişkinin varlığına yönelik araştırmanın yapılabilmesi için yapay sinir ağları (YSA) temelli zeki bir sistem oluşturulmuştur. YSA mimarisi oluşturulurken YSA yapısı ve detayları hakkında bir çalışma yapılmış, yapılan denemeler neticesinde Çok Katlı Perseptron (MLP) yapısının kullanılmasına karar verilmiştir. Daha sonraki denemelerde ise uygun MLP yapısı ve parametreleri elde edilmiştir. 120 kişilik veritabanından rasgele 80 adet kayıt seçilip YSA'nın eğitimi yapılmıştır. Eğitim esnasında sistemin giriş ve çıkışı sırasıyla parmakizlerine ve yüzlere ait özellik setleridir. Sisteme giriş olarak bir otomatik parmakizi okuyucudan elde edilen özellikler kullanılmaktadır. Çıkış olarak ise kaş, göz veya dudakların belirlenmesi için işaretlenen noktaların koordinat bilgileri kullanılmıştır. Parmakizi-yüz veritabanında eğitim için kullanılan kişiler dışında kalan 40 kişilik parmakizleri kullanılarak sistem test edilmiş ve sistemin başarımı görülmüştür. Testte kullanılan 40 kişiye ait "arzu edilen çıkış" değerleri yalnızca YSA'dan elde edilen sistem çıkışlarının doğruluklarının analizinde, hataların hesaplanmasında ve sistemin başarımının değerlendirilmesinde kullanılmıştır. Sistemin doğruluk analizi okh (mean square error), tkh (sum square error), kişi başı mutlak yüzde hata ve korelasyon gibi parametrelerle değerlendirilmiştir. Ayrıca sistem başarısının daha gerçekçi ve görsel olarak da ifade edilebilmesi için sonuçlar çizilerek de ifade edilmiştir.

Parmakizi ile yüz arasındaki olabilecek ilişkinin analizi ve incelenmesi işlemine parmakizi ve yüz özelliklerini içeren bir ÇBVT oluşturularak başlanmıştır. Sunulan çalışmada 120 kişilik bir parmakizi yüz veritabanı oluşturulmuştur. Bu çalışmada sadece bir adet parmakizi ve her yüze ait sadece bir adet yüz resmi kullanılmıştır. Kişinin sağ el işaret parmağı ile kaşlar, gözler, burun ve ağız olarak sıralanabilen yüze ait temel bileşenler arasındaki ilişkiler dikkate alınmıştır.

Parmakizi ile yüz arasında herhangi bir ilişkinin varlığının araştırılması ve incelenmesi konusunda ikinci öncelik parmakizi ve yüze ait özellik setlerinin doğru ve güvenilir olarak elde edilmesidir. Bu özellik setlerinin doğru olarak elde edilmesi çalışmanın ve sistemin başarısını doğrudan etkileyecek faktörlerdir. Literatürde böyle bir çalışmanın olmayışı ve bu yaklaşımın ilk defa tarafımızdan sunuluyor olması nedeniyle parmakizi ve yüze ait özelliklerin elde edilmesinde kullanılan yöntemlerin şeffaflığı bu çalışma için özellikle önem arz etmektedir. İşte bu nedenden dolayı parmakizi özellik setlerinin oluşturulmasında konu ile ilgilenen herkesin bildiği, doğruluğu ve güvenilirliği onaylanmış, biyometri sektöründe ticari olarak faaliyet gösteren, internetten kolayca erişilebilen bir programın kullanılması uygun görülmüş ve Neurotechnologija tarafından geliştirilen VeriFinger 4.1 SDK kullanılmıştır. Bu şekilde bir seçimin PYTZS için oluşabilecek önyargı ve şüpheleri ortadan kaldıracağı, böylece çalışmanın daha objektif olarak değerlendirilmesi sağlanabilecektir. Parmakizine ait özellik seti ile ilgili detaylar, kayıt şekli ve formatı, özellik setinin elde edilmesinde kullanılan algoritmalar ve bunların işleyiş şekilleri ile ilgili her türlü bilgi VeriFinger SDK'da mevcuttur [18]. Benzer şekilde yüzlere ait özellik setlerinin elde edilmesinde de şeffaf bir yöntem tercih edilmesi gerektiği düşünülmüş, konuyla ilgili literatürde varolan ve yukarıda ana hatlarıyla verilen tüm yüz tanıma yöntemleri incelenmiş, bunlar arasında yüze ait değişmeyen özellikler kullanılarak yüz tanıma yapabilen yöntemlerin kullanılmasının daha doğru olacağı sonucuna varılmıştır. Bunun nedeni ise parmakizinin temsil edilmesinde parmakizinde bulunan ve değişmeyen fiziksel özellikler kullanılmaktadır. Bunun yüz tanımadaki tam karşılığı da yüze ait değişmeyen özellikler olarak tarafımızdan yorumlanmıştır. Bu şekilde bir bakış açısı ile hiçbir karmaşıklığı olmayan, yüzde bulunan ve yüzün tanınmasını sağlayan özelliklerin en basit anlamda elde edilmesi mantığına dayalı bir yöntemin kullanılmasına karar verilmiştir. Literatürde bulunan yüze ait değişmeyen özellikleri temsil eden noktaların kullanıldığı yöntemler incelenmiş, bunlar arasında çalışmanın doğasına uygun bir yöntem belirlenmiştir [19]. Bu yöntemde, göz, dudak, kaş, burun, kulak ve yüz çevresi üzerinde örnek noktalar işaretlenerek alınmıştır. Ancak bu yöntemde kullanılan 35 farklı nokta ile bu noktalar kullanılarak elde edilen parametreler yüz kısımlarının yeterince hassas temsil edilemediği görülmüş ve bu yaklaşımın hassasiyetinin arttırılarak kullanılabilmesi için Şekil 2'de verilen yüze ait özellik setinin 66 noktaya çıkarılması gerektiği sonucuna varılmıştır. Sunulan çalışmada kullanılan yüze ait özellik noktalarının gösterildiği şablon ve noktaların gerçek bir yüz resmi üzerinde yerleştirilmesi Şekil 2(b)'de verilmektedir. Şekil 2(b)'de verilen 66 noktadan kişiye ait robot resmin çizilmesi ve kişinin yüzü ile ilgili karakteristik özelliklere ulaşılması mümkün olmaktadır. Tüm bu işlemleri sorunsuz, hızlı ve başarıyla gerçekleştiren bir yazılım tarafımızdan geliştirilmiştir.

Parmakizi ve yüze ait biyometrik özelliklerin elde edilmesinden sonra PYTZS'de işlem sırası kullanılacak zeki sistemin tasarımına gelmektedir. Bu çalışmada, literatürde hiç çalışılmamış, hakkında en ufak bir bilgiye rastlanmayan, tamamen yeni bir ilişkinin varlığı veya yokluğunun araştırılması

(a) örnek veri seti (example for a data set)



(b) Yüz şablonu (face template)

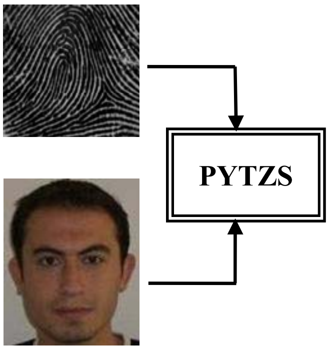
Şekil 2. YSA için örnek veri seti (Example for a data sets)

sözkonusudur. Aradaki ilişkiyi öğrenebilecek zeki sistemin tasarımı ile ilgili bir çalışma yapıldığında problemin doğasına en uygun teknoloji olarak ilk karşımıza çıkan teknoloji YSA olmaktadır. YSA, öğrenme yeteneği, kolayca farklı problemlere uyarlanabilirliği, genelleme yapabilmesi, uygulamada daha az bilgi gerektirmesi, paralel işlem yapabilme gibi özelliklerinden dolayı hızlı çalışabilme yeteneği ve kullanıcının giriş ile çıkış arasındaki ilişkiyi tarif etme mecburiyetinin olmayışı gibi pek çok üstünlükten dolayı, literatürde birçok alana başarıyla uygulanmış bir teknolojidir [20,21]. Belirtilen avantajları bünyesinde barındıran YSA'nın biyometrik sistemlere başarıyla uygulandığı örneklerde mevcuttur [22-24]. PYTZS'nin YSA ile geçekleştirilmesine karar verilmesinin ardından, YSA mimarisi olarak MLP yapısının kullanılmasına karar verilmiştir. MLP en çok kullanılan YSA yapısı olmasının yanında farklı pek çok öğrenme algoritmasıyla da eğitilebildiğinden bu ağın eğitiminde kullanılabilmektedir [21].

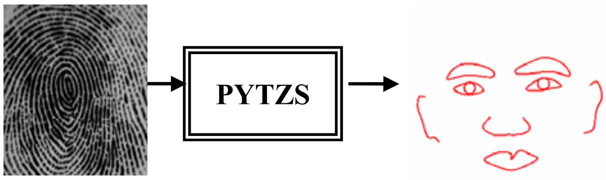
YSA'yı eğitmek için SCG (Scaled Conjugate Gradient) öğrenme algoritması kullanılmıştır. SCG algoritması, ağırlıkları ve giriş değerleri mevcut ve türevi alınabilir transfer fonksiyonlarına sahip olan tüm yapay sinir ağlarının eğitiminde kullanılabilen bir öğrenme algoritmasıdır. Ağırlık ve bias değerleri Conjugate Gradient algoritmasına göre değiştirilmektedir [25]. SCG ise Moller tarafından bu algoritmanın karmaşıklığının giderilerek geliştirilmesi sonucu elde edilmiş bir öğrenme algoritmasıdır [26].

PYTZS'nin tasarımı yapılırken, en basitten karmaşığa doğru belirli bir sistematik içerisinde ilerlenmiş, problemin çözümünde, olabilecek en basit çözümün tercih edilmesine gayret gösterilmiş ve sonuçta çalışma mantığı Şekil 3'te verilen zeki sistem ortaya çıkmıştır.

Tasarımı tamamlanan PYTZS eğitim için hazır hale gelmiştir. Oluşturulan ÇBVT'de 120 kişiden 80'i rasgele seçilerek sistemin eğitiminde, kalan 40 kişi ise sistemin testinde kullanılmıştır. Sistemin giriş çıkışı sırasıyla parmakizlerine ve yüzlere ait özellik setleridir. 298 ve 132 boyutlarındaki bu özellik setleri aynı kişinin parmakizini ve yüzünü temsil etmektedir. Bu şekilde kişilerin parmakizlerine ait özellik setlerinin giriş, yüzlerine ait özellik setlerinin de çıkış olarak sisteme girilmesiyle eğitim işlemi gerçekleştirilmektedir. Biyometrik özellikler, önceki paragraflarda açıklandığı şekilde işlemlerden geçirilip özellik setleri elde edilmekte ve bu setlerle sistem eğitilmektedir. Eğitimi tamamlanan sistemin başarısı ise sistemin test sonuçlarının analiz edilmesiyle ortaya çıkmaktadır. Eğitimde hem parmakizine ait özellik setleri hem de yüze ait özellik setleri kullanılmasına karşın testte sadece parmakizlerine ait özellik setleri yeterli olmaktadır. Sistemin test edilmesinin ardından test sonuçlarının değerlendirilmesi ve PYTZS'nin başarımının hesaplanması gerekmektedir. Test sonuçlarının değerlendirilmesinde ortalama karesel



a) Eğitim işlemi (Training process)



b) Test işlemi (Test process)

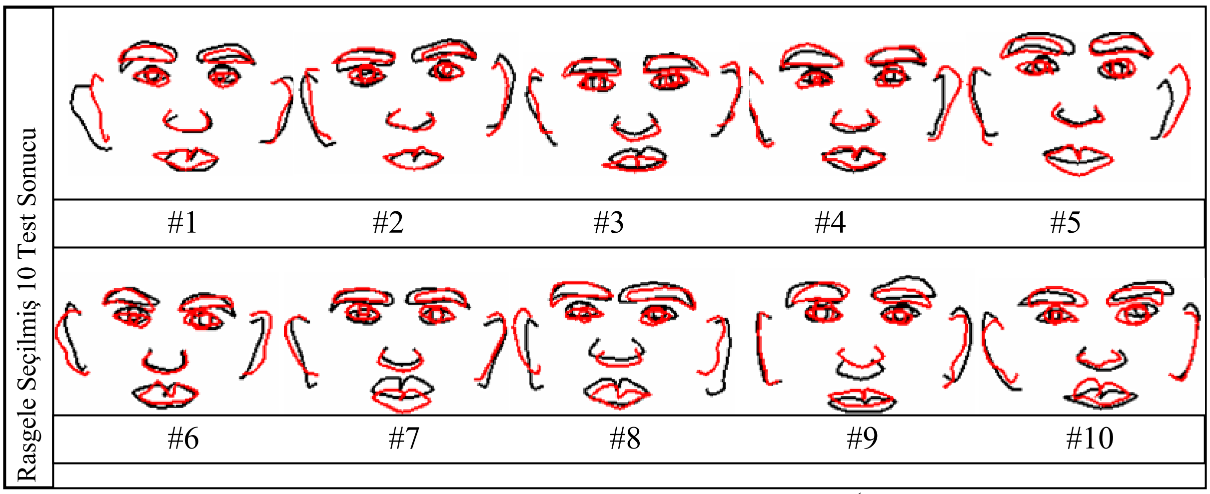
Şekil 3. PYTZS'de YSA işlemleri (ANN processes in PYTZS)

hata (okh), toplam karesel hata (tkh), her test kişisi için mutlak yüzde hata (myh) ve ortalama myh gibi ölçütler kullanılmıştır. Ancak sunulan sistemin klasik bir biyometrik tanıma/onaylama sistemi olmayışı, test sonuçlarının değerlendirilmesinde bu ölçütlerin tek başına yeterli olmadığı sonucunu doğurmuş ve bu ölçütlere ek olarak bazı parametrelerin de kullanılmasını zorunlu kılmıştır. Dolayısıyla bu parametrelerin yanısıra YSA'dan elde edilen sonuçların, arzu edilen sonuçlarla aynı platformda ve test kişilerinin gerçek yüz resimleri üzerinde çizilmesi şeklinde ifade edilerek sistem başarısının görsel olarak da değerlendirilebilmesine olanak sağlanmıştır.

4. DENEYSEL SONUÇLAR (EXPERIMENTAL RESULTS)

Bu çalışmada yalnızca parmakizi resimleri kullanarak, yüze ait hiçbir bilgiye sahip olmaksızın yüz robot resimlerin elde edilmesine yönelik YSA temelli zeki bir sistem tasarlanmıştır. PYTZS'yi gerçekleştirmek için gereken tüm işlemlerin doğru, hızlı ve verimli bir şekilde gerçekleştirilebilmesi için bir yazılım geliştirilmiş ve tüm işlemler bu yazılım yardımıyla gerçekleştirilmiştir. Sunulan çalışma için yüz verilerinin doğruluğunun değerlendirilmesi kritik önem taşımaktadır. Çünkü sistem çıkışı yüze ait özellik setleridir ve sistem bunları ne kadar doğru bulursa performansı o kadar doğru olacaktır. Başka bir ifadeyle yüze ait elde edilen sonuçların doğruluk analizi aslında komple sistemin doğruluğunu ifade etmektedir.

PYTZS'nin başarıyla tasarlanması, sunulması ve sonuçlarının değerlendirilmesi için oluşturulan ÇBVT kullanılarak elde edilen sonuçlar okh, tkh ve ortalama myh değerleri sırasıyla 0.0011, 5.6280 ve 6.195175 şeklindedir. Daha gerçekçi ve görsel bir değerlendirme için YSA'dan elde edilen sonuçların "arzu edilen sonuçlar"la Şekil 4'te verildiği gibi aynı platformda çizilerek gösterilmiş, aynı kişilerin



Şekil 4. Sunulan sistemden elde edilen 10 test sonucu ile arzu edilen sonuçlar (Selected 10 test results with their desired faces of the system.)

YSA'dan elde edilen sonuçlarının gerçek yüz resimleri üzerinde çizilerek gösterilmesi ise Şekil 5'te verilmiştir.

Sayfa sayısı konusunda oluşabilecek problemlerden dolayı test çıkışlarının tamamının şekil olarak gösterilmesi burada mümkün olmamaktadır. Sistem performansının ortaya konulabilmesi için tüm test sonuçlarının kişi başı mutlak yüzde hata değerleri Şekil 6'da sunulan grafikte verilmiştir.

Sonuç olarak sunulan sisteme ait verilen grafikler, şekiller, hata ve benzerlik oranları incelendiğinde yalnızca parmakizi bilgileri kullanılarak kişilerin yüzlerinin kabul edilebilir doğrulukla tahmin edilebiliyor olması kişiye ait olan ve uzun zamandır kişinin kimliklendirilmesinde güvenle kullanılan bu iki biyometrik özellik arasında yakın bir ilişkinin olduğunu ve bu ilişkinin modellenerek matematiksel olarak da ifade edilebileceğini, dolayısıyla bu konunun üzerine gidilmesi gerekmektedir.

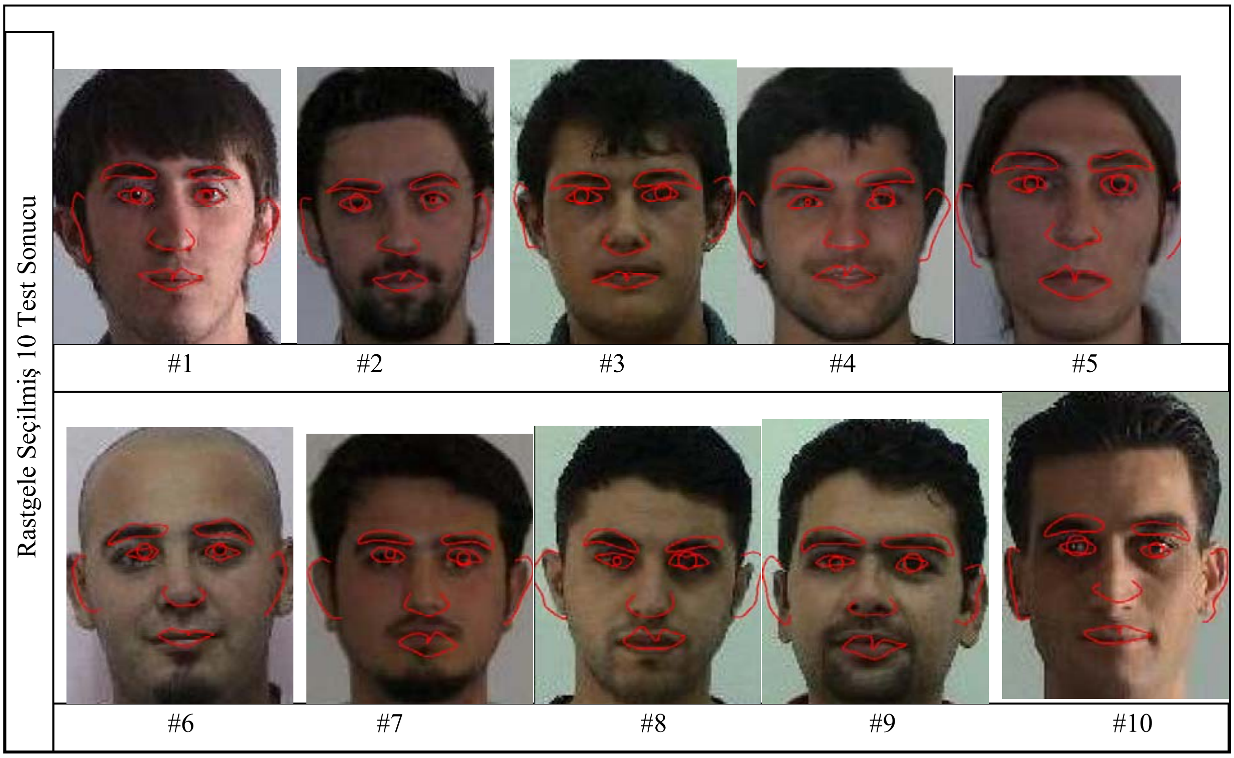
Bu sonuçlar parmakizi ve yüz biyometrik özellikleri arasında ilişkinin olduğunu göstermekte, kimliklendirme ve güvenlik alanında çığır açacak bu ilişkinin diğer biyometrik özellikler arasında da olabileceğinin de işaretini vermektedir. PYTZS daha önce hiç bir bilim insanı tarafından araştırılmayan bir konunun incelenmesi açısından oldukça önemlidir.

Şekil 6. Elde edilen yüzde mutlak hata test sonuçları (Figure 6. Absolute errors in percentages for all test results)

5. SONUÇ VE TARTIŞMA (CONCLUSION AND DISCUSSION)

Bu çalışmada kişiye ait bir parmakizi resmini kullanarak aynı kişinin yüz robot resmini çizmeye yönelik bir sistem bütün olarak sunulmaktadır. Elde edilen sonuçlar parmakizi ve yüz gibi biyometrik iki özellik arasında yakın bir ilişkinin varlığını ortaya koymakta, bu ilişkinin boyutu ve çeşidi ise bundan sonraki araştırmalara kalmaktadır. Konuyla ilgili tartışmalar aşağıdaki başlıklarda verilmektedir.

I. Sunulan çalışma diğer biyometrikler arasında olabilecek herhangi bir ilişkinin analiz edilmesinde öncülük edebilecek niteliktedir.
II. Şekil 6'da sunulan sonuçlarda bazı değerlerin yüksek çıkması ve bazı sonuçlarda düşük hata elde edilmesinin sebepleri ise parmakizleri ile yüzler arasında oluşturulan modelin bazı parmak izleri için iyi performans göstermemesinden kaynaklanmaktadır. Yüksek hata dağerine sahip olan yüz resimleri ile düşük hata değerlerine



Şekil 5. Sistemin elde ettiği test sonuçlarının kişinin resmi üzerinde gösterilmesi (Randomly selected 10 test results on real face images)

sahip yüz resimlerinin benzerlikleri üzerinde kapsamlı çalışma yapılarak bu husus somut olarak açıklanmasına ihtiyaç vardır.

III. PYTZS'de kullanılan yaklaşım, biyometrik sistemler, güvenlik, kimliklendirme, suç ve suçlu takibi ve benzeri birçok alana yeni araştırma alanları ekleyecek niteliktedir.

IV. Bu çalışma ile biyometrik sistemlere araştırmacıların ilgisini yeniden çekecek oldukça ilginç fikirler sunulmaktadır.

V. Sunulan çalışmada elde edilen sonuçlar robot resim şeklindedir ve bu çıkışlar hiç bir son işlem yapılmadan en ham halleri ile sunulmuşlardır. Bu çıkışları bazı son işlemlere tabi tutularak sonuçlar iyileştirilebilecektir.

VI. Robot resim şeklindeki çıkışların literatürde bilinen ve kullanılan çeşitli teknikler ve programlar yardımıyla resim şekline getirilmesi, üç boyutlu hale çevrilerek görselliği ve doğruluğunun arttırılması mümkündür.

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An intelligent face features generation system from fingerprints

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Abstract

In this study, a novel intelligent system based on artificial neural networks was designed and introduced for generating faces from fingerprints with high accuracy. The proposed system has a number of modules including two feature enrolment modules for acquiring the fingerprints and faces into the system, two feature extractors for extracting the feature sets of fingerprint and face biometrics, an artificial neural network module that was configured with the help of Taguchi experimental design method for establishing relationships among the biometric features, a face re-constructor for building up face features from the results of the system, and a test module for test the results of the system. 10-fold cross validation technique was used for evaluating the performance of the system. The results have shown that the face features can be successfully generated from only fingerprints. It can be concluded that the proposed study significantly and directly contributes to biometrics and its new applications.

Key Words: *Information security, biometrics, artificial neural networks.*

1. Introduction

Accurately identifying a person is the most critical process in biometrics-based security applications, and are used for recognizing and determining an individual identity based on his or her physical or behavioral characteristics, including fingerprint, face, ear, hand geometry, voice, retina, iris, etc. [1, 2]. Any human physiological or behavioral characteristic might be used as a biometric characteristic as long as it satisfies these following requirements: universality, uniqueness, permanence and collectability [2]. Biometric based identification systems have been widely utilized in many security applications. Biometrics is a marvelous technology that is lower in cost, faster and more accurate. It also covers the great performance expectations compared with the existing alternatives like PINs or passwords [1]. Over the last couple of decades, biometric based recognition systems have been widely investigated, a number of biometric features have been studied, tested, and successfully deployed in applications including information security, law enforcement, surveillance, forensics, smart cards, access control, time/place control points and computer networks, etc. [2], [3].

Achieving a biometric feature from another biometric feature is a challenging idea. This transformation might be useful for many applications especially security applications. When the literature was reviewed, no study was found investigating relationships among the biometric features or obtaining one feature from the others, except the present authors [4–12]. Sağıroğlu and Özkaya have experimentally showed there exists a relationship among the biometric features of faces and fingerprints. The authors proposed novel approaches for generating the face borders [4], the face contours including face border and ears [5], the face models including eyebrows, eyes and mouth [6], the inner face parts including eyes, nose and mouth [7], the face parts including eyes, nose, mouth and ears [8], the face models including eyes, nose, mouth, ears and face border [9], the face parts including eyebrows, eyes, nose, mouth and ears [10], only eyes [11] and the face parts including eyebrows, eyes and nose [12] from only fingerprints without any need for face information or images. It is clear from the studies that an unknown biometric feature can be achieved from a known biometric feature.

The scope of our study here is to develop an automatic and intelligent biometric system capable of obtaining inner face features including eyes, nose and mouth from just fingerprints, without having any priori knowledge about faces, with the help of optimally designed artificial neural network (ANN) models. In order to achieve that, an intelligent face model generation system from fingerprints (fingerprint to face features: F2FF) was developed and introduced in this study. The ANN models used for establishing the relationships among fingerprints and faces were optimally designed with Taguchi experimental design technique.

This paper is organized as follows. Section II briefly describes background information on biometrics, automatic fingerprint identification and verification systems (AFIVSs), face recognition systems (FRSs) and multi modal biometric systems (MMBSs), respectively. Sections III and IV briefly introduce ANNs and Taguchi experimental design technique, respectively. Section V highlights the novelty of the proposed technique, presents basic notation, definitions, performance metrics related to the F2FFs and explains the steps of the proposed approach followed. Section VI demonstrates the experimental results achieved in this study. Finally, the proposed approach is concluded and discussed in Section VII.

2. Overview of biometrics

Biometrics is used to recognize an individual or to determine an individual identity based on his/her physical or behavioral biometric characteristics [2]. In general, a biometric system operates its tasks in the following three steps: acquiring biometric data from a person, extracting a feature set from the acquired data, and recording the feature set into a database or/and comparing the feature set against the template feature set in the database. When a user wants to authenticate him/herself to the system, a fresh biometric feature is taken from the user, the same feature extraction algorithm is applied, and the extracted feature set is compared to the template. If they are sufficiently similar according to the criterion, the user is finally authenticated [13]. Biometric based systems lead to user convenience, reduce fraud and secure systems and society [14]. Figure 1 illustrates a general biometric system having four modes depending on the application status [14]: the enrolment, the verification, the identification and the screening.

The two most popular biometric systems are AFIVSs and FRSs. Fingerprint is a sort of identity card that

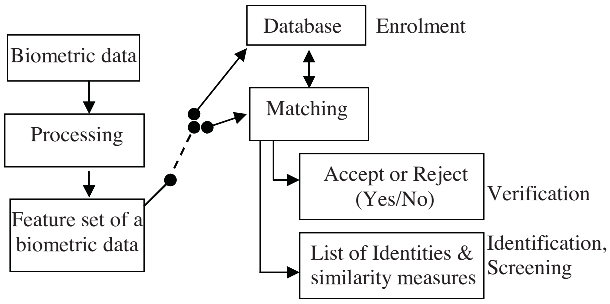


Figure 1. A generic biometric system.

people carry with them continuously [15]. The AFIVSs might be broadly classified as being *minutiae-based, correlation-based* and *image-based* systems [16]. A good survey about these systems is given in [2]. In our study, feature sets of the fingerprints a minutiae-based approach was preferred. The minutiae-based approach rely on the comparison for similarities and differences of local ridge attributes and their relationships to make a personal identification [17, 18]. In general the comparison is based on representing two important attributes including end points and bifurcations. The end point is defined as the point where a ridge ends suddenly. A bifurcation is defined as the point where a ridge separates or diverges into branch ridges [3, 17]. If these local attributes and their parameters are computed relative to the global attributes called singular points including core and delta points which are highly stable, rotation, translation and scale invariant, these local attributes will then also become rotation, translation and scale invariant [19], [20–22]. Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate [21, 23]. Main steps of the operations in the minutiae-based AFIVSs are summarized as follows: selecting the image area, detecting the singular points, enhancing, improving and thinning the fingerprint image, extracting the minutiae points and calculating their parameters, eliminating the false minutiae points, representing the fingerprint images properly with their feature sets, recording the feature sets into a database, matching the feature sets, testing the system results and evaluating the performance of the system. The performance of the minutiae-based techniques relies on the accuracy of all these processes. Especially the feature extraction and the use of sophisticated matching techniques to compare two minutiae sets often affect the performance.

Face recognition is a biometric method that identifies the individuals using the features of their faces. It is an active research area with applications ranging from static, controlled mug-shot verification to dynamic, uncontrolled face identification in a cluttered background [17]. In general, a FRS consists of three main steps. These steps cover detection of the faces in a complicated background, localization of the faces followed by extraction of the features from the face regions and finally identification or verification tasks [24]. Face recognition process is really complex and difficult due to numerous factors effecting the appearance of an individual's facial features such as 3D pose, facial expression, hair style, make up, lighting, background, scale, noise and face occlusion [24, 25]. The most popular approaches to face recognition are based on either the location and shape of the facial attributes [26] or the overall analysis of the face images [14, 24]. Also many effective and robust methods for face recognition have been proposed in the literature [3, 17], [24–29].

Multi-model biometric systems (MMBSs) are gaining acceptance among designers due to their performance superiority over the unimodal systems that have some limitations about accuracy, processing time and vulnerability to spoofing [28]. The advantages of multimodal biometrics have been reported with repetition in the literature. It is indicated that combining multiple sensors, biometric features, units, matchers or enrolment templates of a user could improve the accuracy of a biometric system [30]. Also MMBSs were designed as a fusion of the various biometric data at different levels such as the feature extraction level, the score level or the decision level [31]. Detailed information about MMBSs can be found in [13].

3. Artificial neural network

Artificial neural networks have been applied to solve many problems in the literature [27, 32–37]. Learning, generalization, less data requirement, fast computation, ease of implementation and software and hardware availability features have made the ANNs very attractive for many applications [33, 34]. These fascinating features have also made them popular in biometrics as well [27, 32, 35–37]. Multilayered perceptron (MLP) is one of the most popular ANN architectures used in biometrics.

MLP structures consist of three layers: input, output and hidden layers. One or more hidden layers might be used. The weights are adapted with the help of a learning algorithm according to the error occurring in the calculation. The error can be calculated by subtracting the ANN output from the desired output. ANNs might be trained with many different learning algorithms [33]. To get better and faster performance, Taguchi experimental design technique was used to achieve optimum parameters of ANN structure, in this study.

4. Taguchi experimental design technique

The Taguchi experimental design technique is a well-known and robust design technique [38–41] involving an efficient planning of experiments in engineering applications [40]. This technique enables the optimum combination of design parameters to be determined from a minimum number of experiments, ensures the reproducibility of the experimental results and recommends devising a smallest possible fractional factorial design. With the help of this technique [40]:

1. The performance characteristics to be optimized are selected.

2. The experiments based on orthogonal array to obtain information on the system performance and its variability are designed and executed.

3. Mean and variance techniques to obtain optimal setting of parameters for robust system design are analyzed and used.

The results from the experimental runs can provide information in the form of the deviation from the mean of a set [41]. Verification of the robust design results is then performed [40]. Analyses of means are used to determine the best ANN parameters to achieve optimal performance. Analysis of variance is also used to determine the factors that have significant effects on the signal-to-noise ratio (SNR) [41].

5. Proposed system

As briefly expressed in the previous sections, fingerprint verification and face recognition topics have been received significantly more attention. The aims of this study are to establish a relationship among fingerprints and faces (Fs&Fs), to analyze this relationship and to generate the face features from fingerprints, requiring no priori knowledge about faces, using a system equipped with the best parameter settings. The majority of these aims were achieved in this work.

Our motivation in this study arises from biological and physiological conditions, as briefly reviewed below.

It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment [42]. Physical appearances of faces and fingerprints are also a part of an individual's phenotype. In the case of fingerprints, the genes determine the general characteristics of the pattern [42]. In dermatoglyphics studies, the maximum generic difference between fingerprints has been found among individuals of different races. Unrelated persons of the same race have very little generic similarity in their fingerprints, parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in the identical twins, which have the closest genetic relationship [43]. Some scientists in biometrics field have focused on analyzing the similarities in fingerprint minutiae patterns in identical twin fingers [42], and have confirmed the claim that the fingerprints of identical twins have a large class correlation. In addition to this class correlation, other correlations based on generic attributes of the fingerprints such as ridge count, ridge width, ridge separation and ridge depth were also found to be significant in identical twins [42].

In the case of faces, the situation is very similar with the fingerprints. The general characteristics of the face patterns were determined by the genes and the maximum generic difference between faces has been found among individuals of different races. Very little generic similarity was found in the faces of unrelated persons of the same race. Parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in the identical twins, which bear the closest genetic relationship.

A number of studies have especially focused on analyzing the significant correlation among faces and fingerprints of the identical twins [42, 44–46]. The large correlation among biometrics of identical twins was repeatedly indicated in the literature by declaring that identical twins would cause vulnerability problems in biometrics based security applications [47]. For example, the similarity measure of identical twin fingerprints is reported as much as 95% [47]. In the case of faces of identical twins, the situation is very similar. The reason of this high degree similarity measure was explained in some studies as: identical twins have identical DNA except for the generally undetectable micro mutations that begin as soon as the cell starts dividing. Fingerprints and faces of identical twins start their development from the same DNA, so they show considerable generic similarity [48]. The similarity among biometric features of identical twins is given in Figure 2. Fingerprints of identical twins and a fingerprint of a stranger are given in Figure 3 [46].

Generally, it is a simple process for an individual to distinguish the fingerprints or faces of different people. However, distinguishing the fingerprints or faces of identical twins is a very difficult and complicated process, not only for the eyes and brain of a human being but also for biometric based recognition systems. The high degree of similarity in fingerprints and faces of identical twins, of examples are shown in Figure 4, converts this simple recognition process to a hard task.

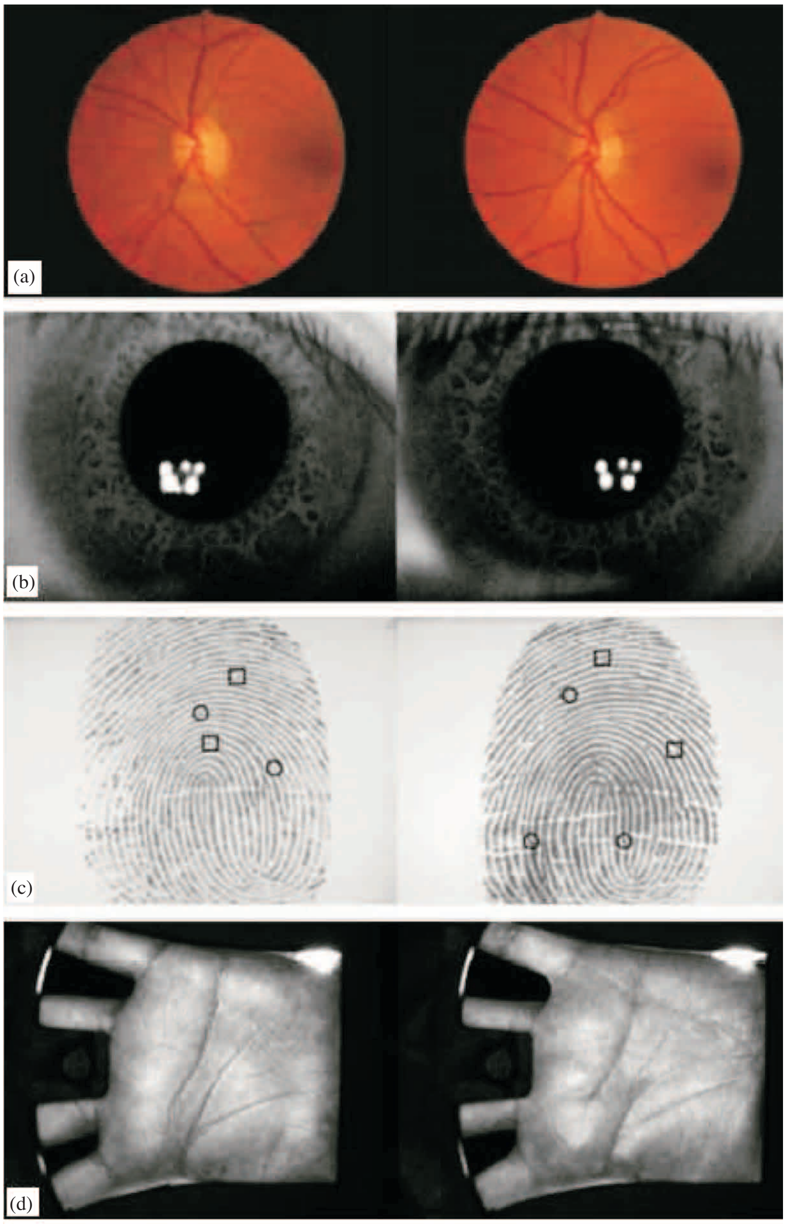


Figure 2. Different biometrics of identical twins [45]. (a) Retina, (b) Iris, (c) Fingerprint (d) Palm print.

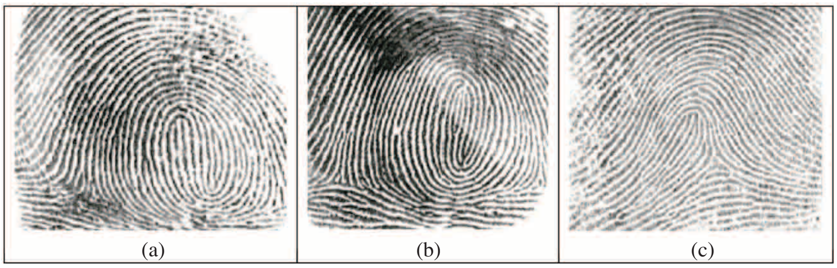


Figure 3. Fingerprints of identical twins (a, b) and fingerprint of someone not related (c) [46].

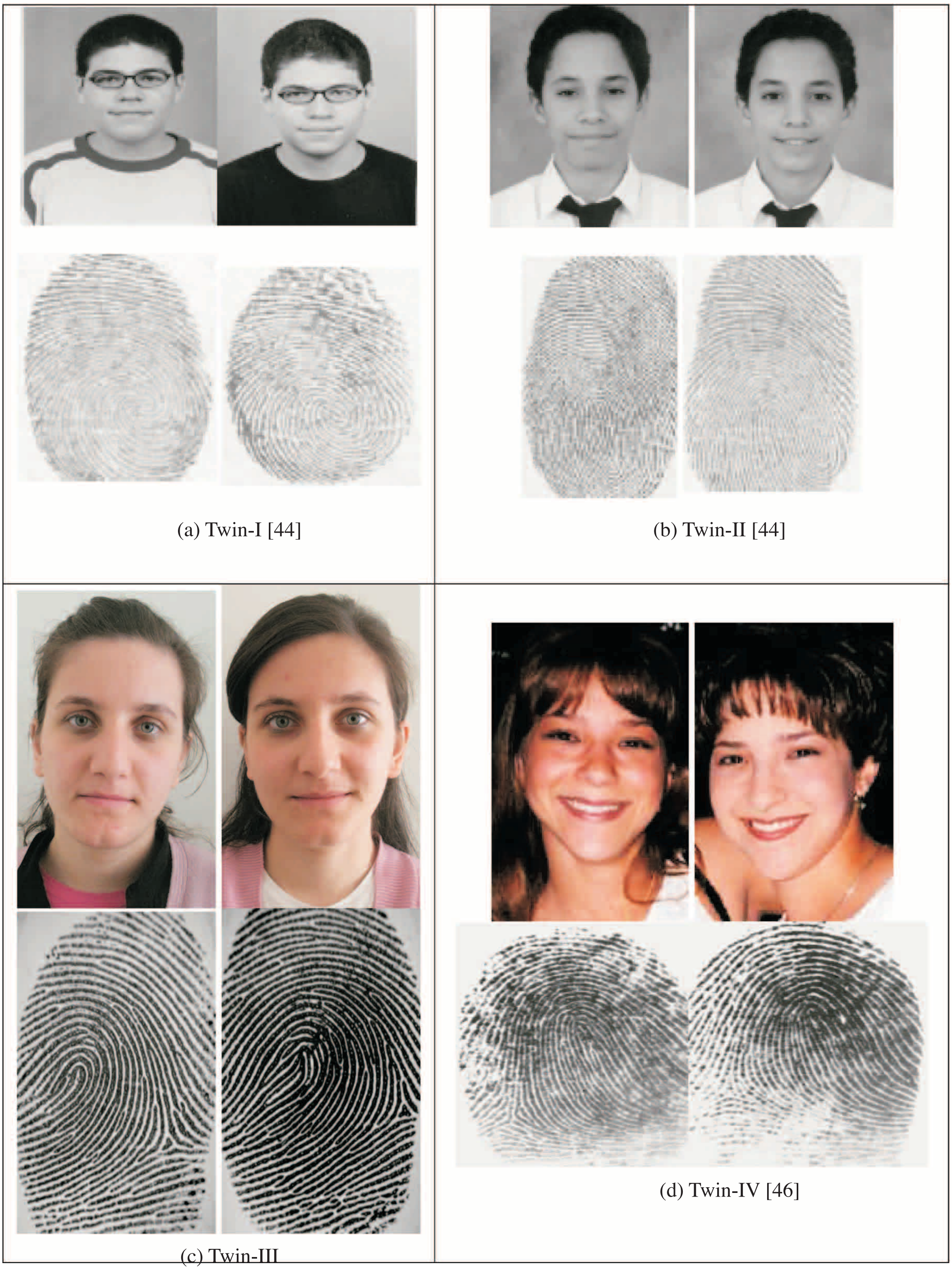


Figure 4. Fingerprints and faces of identical twins.

In the light of the explanations above, identical twins possess strong similarity in both fingerprints and faces. Increasing and decreasing distinctions of such similarities are also the same among non-related people. Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces. In order to investigate this assumption, an intelligent system was developed in this study. Developed ANN based intelligent system generates the inner face features including *eyes, nose and mouth* of an individual from only one fingerprint of the same individual. The system consists of two data enrolment modules, two feature extraction modules, an ANN module, a test and evaluation module and a face re-construction module. In the system, the data enrolment modules help to store biometric data of individuals into the biometric system database. During this process, Fs&Fs of individuals have been captured. Two types of data are used in this study. A real multi-modal database including Fs&Fs belonging to 120 people was established with the help of Biometrica model FX2000 for fingerprints and a Canon digital camera for faces. Only a frontal face image and index finger of the right hand were taken into consideration in this study.

The feature extraction modules were used to extract discriminative feature sets from the acquired data. In the fingerprint feature extraction module, extracting local and global feature sets of the fingerprints, including singularities, minutiae points and their parameters was achieved. Fingerprint feature sets were computed using a software development kit (SDK) developed by Neurotechnologija, ans was selected to establish objective assessment for the F2FF prediction. This SDK is known as an effective, robust and reliable AFIVS in the field of biometrics and uses a minutiae-based algorithm. Detailed explanation of algorithms, information of fingerprint feature sets and their storage format are given in [49]. Face feature sets were obtained from the faces in face feature extraction module. 38 reference points were used for representing a face model in this work. To obtain the face feature sets, a feature-based face feature extraction algorithm was borrowed from Cox et al. [29] and it was fundamentally modified and adapted to this system. In comparison to the approach proposed in [29], increasing the number of reference points helped to represent the faces more accurately and sensitively. In addition, in this study face feature sets were shaped from x-y coordinates of the face model reference points, not distances or average measures as in [29]. It was also observed that feature sets having enough information about faces increase the system's performance on achieving faces accurately. The reason why a feature-based method was preferred for obtaining the feature sets of the faces might be explained as follows: a minutiae-based approach was used to get the feature sets of the fingerprints. Actually, minutiae-based approaches rely on the physical features of the fingerprints. Therefore it is reasonable that the feature sets of both Fs&Fs should be obtained in the same way. Because of these reasons, a feature-based approach was used to obtain the feature sets of the faces as well.

The ANN module is used to analyze the existence of any relationship among Fs&Fs. This part of the system was implemented with the help of MLP structure. MLPs were trained with the input vectors and the corresponding output vectors with different parameter levels based on Mean Square Errors (MSEs) and Absolute Percentage Errors (APEs). In order to determine the best parameter settings of MLP structure, L-16 (8** 1 2** 3) Taguchi experiment is designed. Taguchi design factors and factor levels are given in Table 1. Training algorithms, the number of layers, the number of inputs and the transfer functions were main Taguchi design factors to be considered. Levels of Taguchi design factors were 8, 2, 2 and 2, respectively. MLP training algorithms that have been considered and used in this work were Powell-Beale conjugate gradient back propagation (CGB), Fletcher-Powell conjugate gradient (CGF), Polak-Ribiere conjugate gradient (CGP), Gradient descent (GD), Gradient descent with adaptive learning coefficients (GDA), One step secant (OSS), GDA with momentum and adaptive learning coefficients (GDAM) and Scaled conjugate gradient (SCG). In this study, the number of layers was 3 and 4; and the number of inputs was 200 and 300. The transfer functions that have been considered and used were Tangent Hyperbolic (TH) and Sigmoid Function (SF).

Table 1. Taguchi design factors and factor levels.

Taguchi Design		Levels							
		1	2	3	4	5	6	7	8
Design Factors	Training Algorithms	CGB	CGF	CGP	GD	GDA	OSS	GDAM	SCG
	Number of Layers	3	4						
	Number of Inputs	200	300						
	Transfer Functions	TH	SF						

Via Taguchi design, the best MLP parameters were determined according to the MSEs. Main effects plots were taken into consideration while analyzing the effects of parameters on response factor. The main effects plots for this study are given in Figure 5 and Figure 6. They show the effects of each factor to the response factor, both in numerical and graphical representation. Plots of the main effects might help to understand and to compare changes in the level means, and to indicate the influence of effective factors more precisely. When the line is parallel to the x-axis, it means that each level of the factor affects the response in the same way and there is no main effect. When the line has a slope, then a main effect exists and different levels of the factor effect the response differently. Greater slopes display the magnitude of the main effects. By comparing the slopes of the lines, relative magnitude of the factor can be determined. Smaller values are better in Figure 5, and larger values are better in Figure 6.

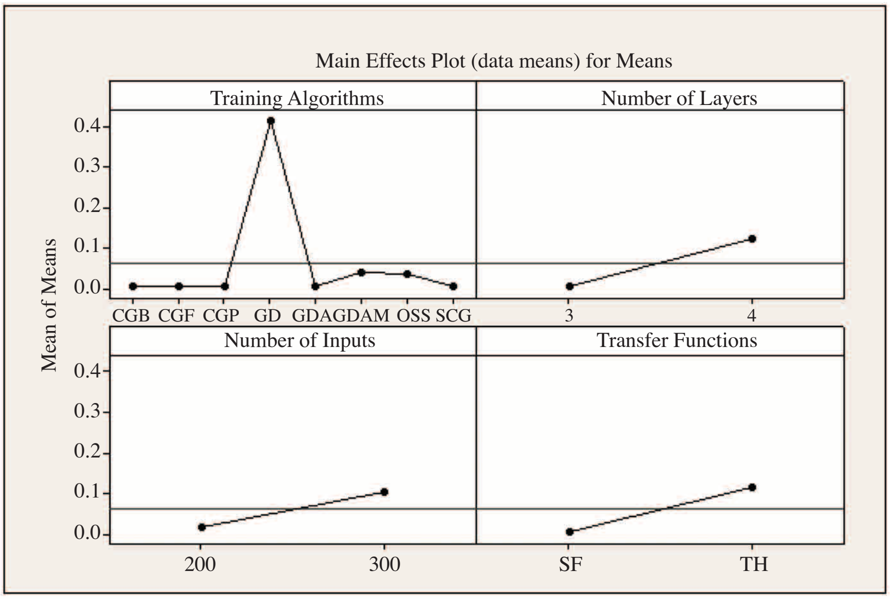


Figure 5. Result table for mean of Means.

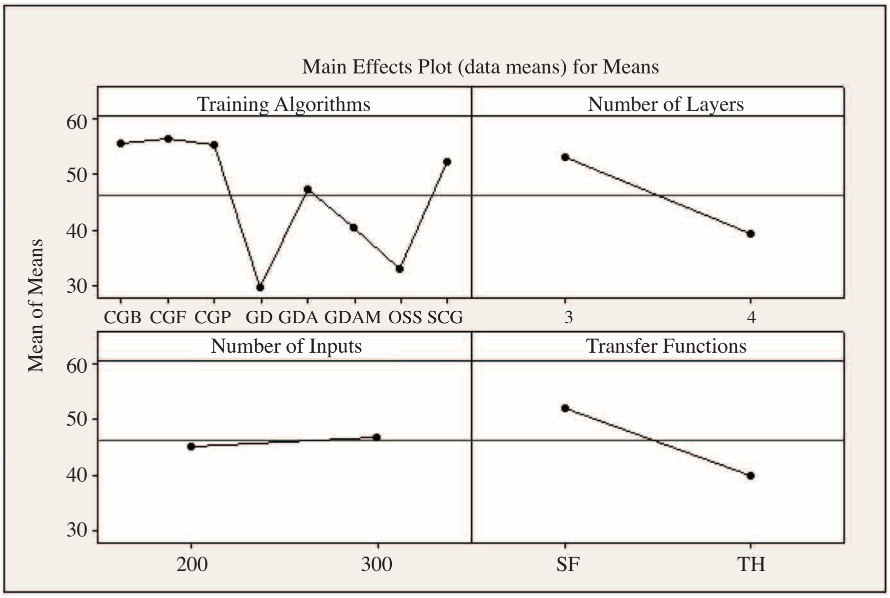


Figure 6. Result table for mean of SNR.

As can be seen from Figure 5, training algorithms have the largest main effect on MSE. Also, all other factors have considerably effected to the system performance according to the main effects plot for means. However, only this plot is not enough to derive a conclusion, for it is necessary to consider the main effects plot for SNR that is given in Figure 6.

In this work, the main effects plot for SNR has confirmed that the training algorithm has the largest main effect on the response factor. The number of layers in MLP structure and transfer function is also considerably effective. MSE was not mainly effected by the number of inputs. Finally it can be clearly said that considering the main effects plots, MSEs will get smaller if the parameter settings given in Table 2 were followed.

Table 2. Results for ANN factors.

Factors	Parameter Settings		
	Means	SNR	Optimum Design
Training Algorithm	CGF	CGF	CGF
Number of Layers	3	3	3
Number of Inputs	200	300	300
Transfer Functions	SF	SF	SF

The CGF algorithm was determined the best training algorithm in the ANN parameter analysis in Taguchi design technique. The CGF algorithm updates weights and biases according to the conjugate gradient with Fletcher-Reeves updates. This algorithm calculates the mutually conjugate directions of search with respect to the Hessian matrix of f directly from the function evaluation and the gradient evaluation, but without the direct evaluation of the Hessian of the function f [50]. This algorithm is defined as follows [50]:

1 : *repeat*
2 : $Compute\ \nabla f(x^0)\ and\ h^0 = \nabla f(x^0)$

3 : $for\ i = 1, ..., n-1\ do$

4 : $replace\ x^i = x^{i-1} + \lambda^{i-1}h^{i-1},$

where λ^{i-1} minimizes $f(x^{i-1} + \lambda^{i-1}h^{i-1})$

5 : $Compute\ \nabla f(x^i)$

6 : if $i < n$ then

7: $h^i = -\nabla f(x^i) + \frac{\|\nabla f(x^i)\|^2}{\|\nabla f(x^{i-1})\|^2} h^{i-1}$

8 : end if

9: $x^0 = x^n$
10 : end for

11: until halting criterian

The quantity $\frac{\|\nabla f(x^i)\|^2}{\|\nabla f(x^{i-1})\|^2} h^{i-1}$ is added to the gradient at every iteration when f is a quadratic form (positive definite); it results in a set of mutually conjugate vectors. The details of CGF algorithm can be found in references [51] and [52].

The ANN module was the most critical and important module of the system, because all modules of the system except the ANN module are on duty, either in pre-processing or post-processing of the main process. The ANN structure and its training parameters were determined to achieve accurate solutions. The training process was started with applying the fingerprint and face feature sets to the system as inputs and outputs, respectively. The sizes of the input and the output vectors were also 300 and 76, respectively. The size of input (the feature sets of fingerprints) is fixed to 300 because of their different lengths. If the size of input is larger than 300 it is fixed to 300. If the size of inputs is smaller than 300, zeros are added to the string to complete it to 300.

The system achieves the training processes with these feature sets according to the learning algorithm and the ANN parameters which were obtained via the Taguchi design method. Even if the feature sets of Fs&Fs were required in training, only fingerprint feature sets were used in test. It should be emphasized that these fingerprints used in test were to the system totally unknown biometric data. The outputs of the system for the unknown test data indicate the success and reliability of the system. The success and reliability of the system in achieving faces from fingerprints must be clearly shown by evaluating the ANN outputs against to the proper metrics.

In this study, to characterize the performance of the F2FF system, appropriate performance metrics were used. The results of the system were tested and the performance of the system was evaluated in 10-fold cross validation technique using traditional, numerical, graphical and visual evaluation platforms by considering the following metrics:

1. *Traditional Metrics:* These metrics are: false match rate (FMR), false non_match rate (FNMR) and the receiver operating characteristics (ROC) curve. The percentage of the impostor pairs, whose matching score is greater than a threshold value, is called FMR; and the percentage of genuine pairs, whose matching

score is less than the threshold value, is known as FNMR. FMR(t) & FNMR(t) representation is derived from the score distributions at all thresholds t. In the literature, it is more common to use a ROC curve to represent the performance and accuracy of the biometric systems.

2. *Numerical Metrics:* These metrics are: mean squared error (MSE), sum squared error (SSE), mean absolute error (MAE), absolute percentage error (APE) and Mean APE. MSE and SSE are two of the most used metrics to quantify the amount by which an estimator differs from the true value of the quantity being estimated. MSE measures the average of the square of the "error." SSE is the sum of squared predicted values in a standard regression model [53]. In general, less the MSE and SSE, better the model performs in its estimation. As the name suggests, MAE is a quantity used to measure how close forecasts or predictions are to the eventual outcomes [53]. In this study, MAE is an average of the absolute errors per each coordinates of the feature sets of the faces. APE is the measure of accuracy in a fitted time series value. It usually expresses accuracy as a percentage [53, 54]. SSE, MSE, MAE, APE and MAPE (Mean APE) are defined in equations (1)–(5), respectively. In the equations, O_i is the output of the ANN, D_i is the desired value of the O_i and $e_i = D_i - O_i$.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(D_i - O_i)^2 \quad (1)$$

$$SSE = \sum_{i=1}^{n}(D_i - O_i)^2 \quad (2)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|D_i - O_i| = \frac{1}{n}\sum_{i=1}^{n}|e_i| \quad (3)$$

$$APE = \sum_{i=1}^{n}\frac{|D_i - O_i|}{D_i} \quad (4)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|D_i - O_i|}{D_i} \quad (5)$$

3. *Visual Metrics:* To evaluate the system results comprehensively a visual evaluation platform is created by drawing the ANN outputs and the desired outputs in the same form. In order to achieve the visual evaluation easily, effectively and efficiently, a face re-construction module was developed. Face re-construction module is flexible software to convert the ANN outputs and desired outputs to visual face models. Indeed, it basically transforms the reference points of the face models to the lines. The developed software is capable of drawing the results of actual and calculated values of the same face in different platforms, in the same platform or on the real face image of involved individual as well.

Consequently, for a more objective comparison, the performance and accuracy of the system have been evaluated and presented on the basis of the combination of these metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.

6. Experimental results

In order to achieve the experiments, a compact software solution was developed. Dedicated software helps all of the system parts to be controlled properly and conducts the experiments easily and efficiently. The experimental image sets used in the test contain only fingerprint images of the test people. It should be emphasized that those image sets were unknown data sets for the system. As mentioned earlier, the inputs and the outputs of the system were vectors sized 300 and 76, respectively. Producing a face as close to the real one as possible is critical for this study. 10-fold cross validation technique was applied in this study for evaluating the performance. The developed systems were trained and tested 10 times with 10 different data sets. Max's, mean's, min's and Standard deviations (STD DEV) of MSE, SSE, Min's, Max's, Averages and Standard deviations of MAEs, APEs and MAPEs were calculated for each fold and Min's, Max's, Averages and STD DEV's of them were given in Table 3.

Table 3. Results for numerical analysis.

	MAX	MEAN	MIN	STD DEV
MEAN's of APEs	5.44755	4.66573	3.95484	0.57996
MAX's of APEs	14.42700	8.84229	5.98220	3.35286
MIN's APEs	3.64400	2.56562	1.88900	0.51441
STD DEV's of APEs	3.40146	1.85673	1.09255	0.86028
MSEs	0.00086	0.00050	0.00064	0.00013
SSEs	0.78660	0.45800	0.58511	0.11938
MEAN's MAEs	0.02290	0.01993	0.01796	0.00197
MAX's MAEs	0.04745	0.03311	0.02553	0.00725
MIN's MAEs	0.01641	0.01134	0.00861	0.00234
STD DEV's of MAEs	0.01020	0.00682	0.00474	0.00185
MEAN's of MAPEs	0.07168	0.06139	0.05204	0.00763
MAX's of MAPEs	0.18983	0.11635	0.07871	0.04412
MIN's MAPEs	0.04795	0.03376	0.02486	0.00677
STD DEV's of MAPEs	0.04476	0.02443	0.01438	0.01132

In order to illustrate the accuracy of the proposed approach, obtained results were compared with the results of a previous study presented in [7] which shared the same goal. The comparison results are given in Table 4. Due to 10-fold cross validation technique not used in the previous study, in this comparison, means of 10-fold cross validation results of the proposed approach in this study and the results of the previous study were benchmarked. As shown in Table 4, clearly the proposed approach has better performance than the previous study, with significant superiority in MSE and SSE. Table 4 shows that Taguchi experimental design technique increases the accuracy and performance of the system. In addition, 10-fold cross validation technique obtained the opportunity to measure the robustness and accuracy of the system in a more reliable platform in comparison to previous studies. The results indicate that the proposed system performs the tasks with measures of high similarity to the desired values and its performance is also better than the previous study [7]. The ROC curves of the results for each fold of 10-fold cross validation technique are given in Figure 7. To represent the results in a more realistic format, test results and desired values of them have been drawn together in the same platform and given in Figure 8 for each fold of 10-fold cross validation technique. All evaluation results including traditional, numerical and visual metrics were obtained from the raw ANN results that were scaled in between [0 1], without any post processing like rescaling.

Table 4. Results for MSE and SSE.

	Previous Study [7]	Proposed Approach
MSE	0.00110	0.00050
SSE	3.24160	0.45800

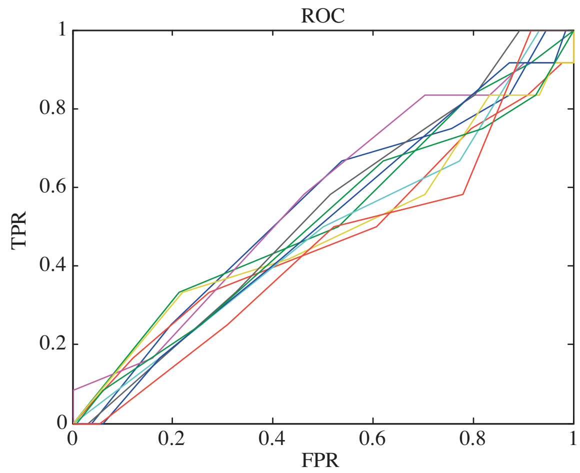
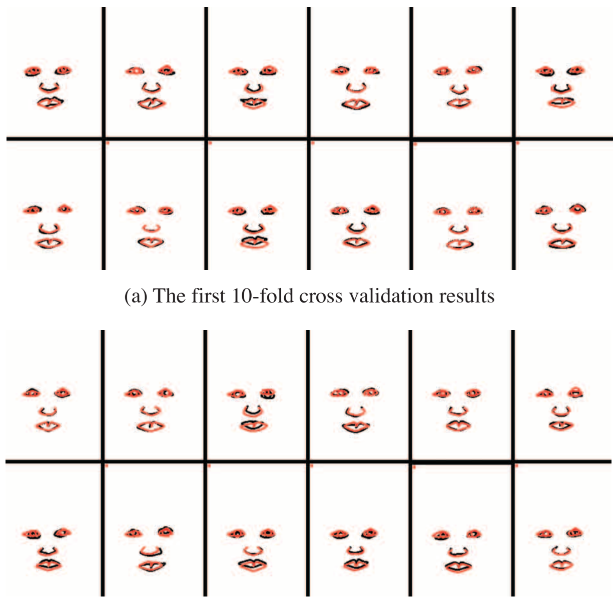


Figure 7. ROC curves of the results for 10-fold cross validation.



(a) The first 10-fold cross validation results

(b) The second 10-fold cross validation results

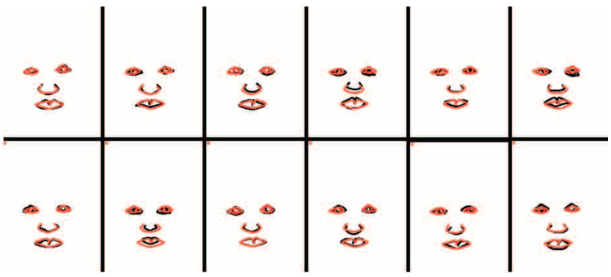
Figure 8. Test results for both desired and achieved face parts for each 10-fold cross validation.

(c) The third 10-fold cross validation results

(d) The fourth 10-fold cross validation results

(e) The fifth 10-fold cross validation results

(f) The sixth 10-fold cross validation results



(g) The seventh 10-fold cross validation results

Figure 8. Contunied.

(h) The eighth 10-fold cross validation results

(i) The ninth 10-fold cross validation results

(j) The tenth 10-fold cross validation results

Figure 8. Contunied.

The APE, MAE and MAPE values belonging to all test results for each fold of 10-fold cross validation are shown in Figure 9. Averages of all APEs, MAEs and MAPEs are given in Figure 10.

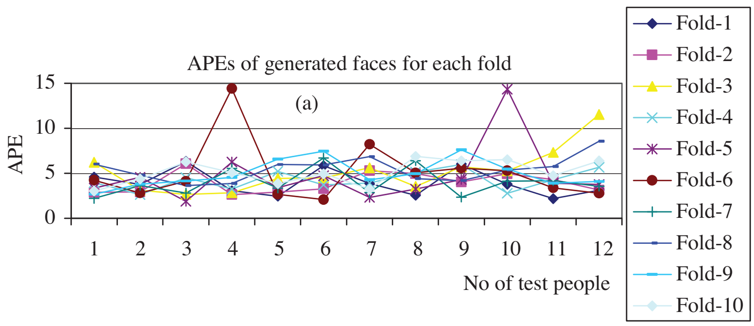


Figure 9. APE, MAE and MAPE values of generated faces.

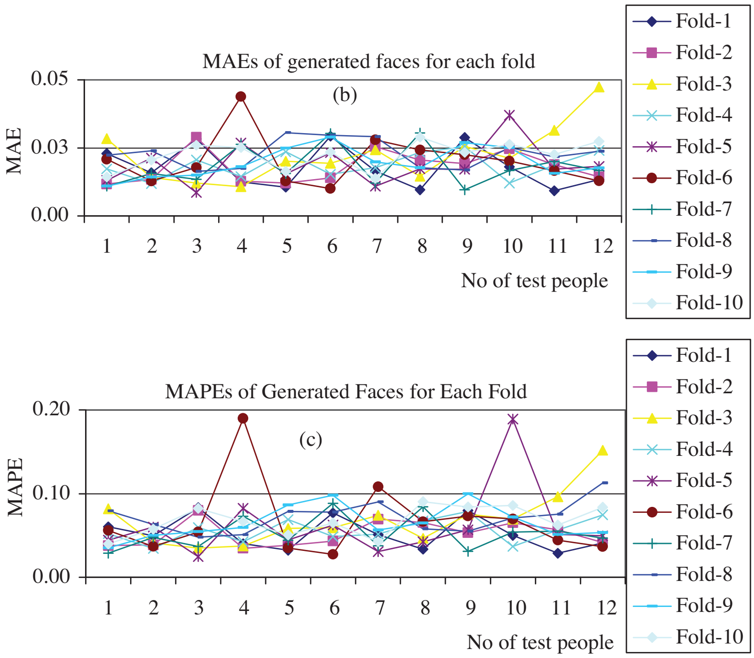


Figure 9. Contunied.

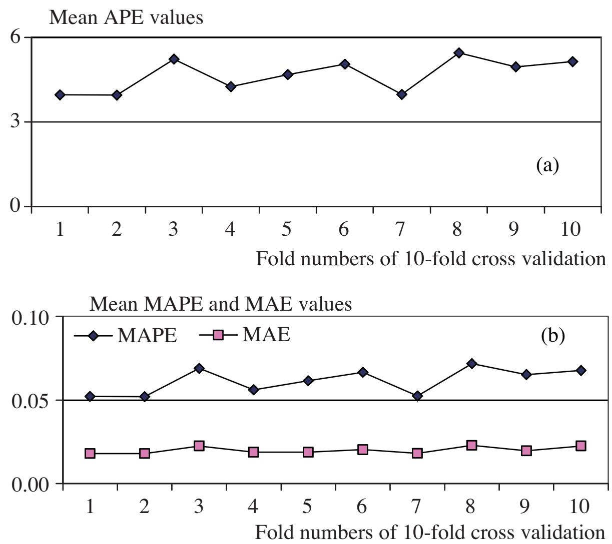


Figure 10. Average results for APEs (a), MAEs and MAPEs (b) for each fold.

The results indicate that the proposed system is very successful in recovering faces from only fingerprints.

7. Conclusion and future work

This study presents a novel approach based on ANN for generating faces from fingerprints without requiring any priori knowledge about faces. The experimental results have shown that Taguchi experimental design technique very much helps design better ANN structures, which achieve better performance, to represent the close relationships among fingerprints and faces. 10-fold cross validation technique has proved the high accuracy of the system in three different evaluation platforms. Owing to 10-fold cross validation technique, the results of the system were evaluated properly, and reliability and robustness of the system were well demonstrated. For example, each fold has more than ten close matches in the nose and mouth areas.

The difficulties faced during the implementation of the system were: establishing a multi-modal database covering fingerprints and faces, the lack of evaluation metrics to determine the results clearly, developing the software throughout the study, applying new concept to the practice, and dealing with many parameters.

It is concluded that the fundamental novelty and diversity of the proposed approach, over most other studies in biometrics, is representation of the relationships among biometric features, such as fingerprints and faces, and to demonstrate the approach which can successfully predict face features from only fingerprints using the ANN that was re-configured with the best parameter settings predicted via the Taguchi experimental design technique. The results have shown that the prediction accuracy improved with the help of Taguchi experimental design method.

The results of this study confirmed once more that there are strong relationships among Fs&Fs. It is expected that this study will lead to create new concepts, research areas, and especially new applications in the field of biometrics and forensics. The authors are studying the modeling of these relationships to demonstrate, not only experimentally, but also mathematically the efficacy of this approach for further studies.

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Article

Generating One Biometric Feature from Another: Faces from Fingerprints

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Abstract: This study presents a new approach based on artificial neural networks for generating one biometric feature (faces) from another (only fingerprints). An automatic and intelligent system was designed and developed to analyze the relationships among fingerprints and faces and also to model and to improve the existence of the relationships. The new proposed system is the first study that generates all parts of the face including eyebrows, eyes, nose, mouth, ears and face border from only fingerprints. It is also unique and different from similar studies recently presented in the literature with some superior features. The parameter settings of the system were achieved with the help of Taguchi experimental design technique. The performance and accuracy of the system have been evaluated with 10-fold cross validation technique using qualitative evaluation metrics in addition to the expanded quantitative evaluation metrics. Consequently, the results were presented on the basis of the combination of these objective and subjective metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances. Experimental results have shown that one biometric feature can be determined from another. These results have once more indicated that there is a strong relationship between fingerprints and faces.

Keywords: biometrics; fingerprint; face; artificial neural network; intelligent system; Taguchi

1. Introduction

Biometrics has become more and more important solutions to overcome vulnerabilities of the security systems for people, companies, corporations, institutions and governments. Person identification systems based on biometrics were used in primarily limited applications requiring high security tasks like criminal identification and police work in the beginning, more recently they have been used in a wide range of applications including information security, law enforcement, surveillance, forensics, smart cards, access control, *etc.* because of their reliability, performance and accuracy of identification and verification processes [1-4]. When the biometric literature was reviewed, it was found that there was extensive literature on fingerprint identification and face recognition. The researchers were mostly focused on designing more secure, hybrid, robust and fast systems with high accuracy by developing more effective and efficient techniques, architectures, approaches, sensors and algorithms or their hybrid combinations [1,2].

Generating a biometric feature from another is a challenging research topic. Generating face characteristics from only fingerprints is an especially interesting and attractive idea for applications. It is thought that this might be used in many security applications. This challenging topic of generating face parts from only fingerprints has been recently introduced for the first time by the authors in series of papers [5-13]. The relationships among biometric features of the faces and fingerprints (Fs&Fs) were experimentally shown in various studies covering the generation of:

- face borders [5],
- face contours, including face border and ears [6],
- face models, including eyebrows, eyes and mouth [7],
- inner face masks including eyes, nose and mouth [8],
- face parts, including eyes, nose, mouth and ears [9],
- face models including eyes, nose, mouth, ears and face border [10],
- face parts, including eyebrows, eyes, nose, mouth and ears [11],
- only eyes [12],
- face parts, including eyebrows, eyes and nose [13],
- face features, including eyes, nose and mouth [14] and
- face shapes, including eyes, mouth and face border [15].

In these studies, face parts are predicted from only fingerprints without any need of face information or images. The studies have experimentally demonstrated that there are close relationships among faces and fingerprints.

Although various feature sets of faces and fingerprints, different parameter settings and reference points were used to achieve the tasks with high accuracy from only fingerprints, obtaining the face parts including the inner face parts with eyebrows and face borders with ears has not been studied up to now. In order to achieve the generation task automatically with high accuracy, a complete system was developed. This system combines all the other recent studies introduced in the literature and provides more complex and specific solutions for generating whole face features from fingerprints. In order to improve the performance of the proposed study, Taguchi experimental design technique was also used to determine best parameters of artificial neural network (ANN) models used in this generation. In order to evaluate and demonstrate the results more precisely, 10-fold cross validation technique with both quantitative (objective) evaluation metrics and expanded qualitative (subjective) evaluation metrics were used. So the performance and accuracy were demonstrated in a more reliable way with a limited database in comparison to the previous studies.

The paper is organized as follows. Section 2 reviews the background information on biometrics, automatic fingerprint identification and verification systems (AFIVSs), and face recognition systems (FRSs). Section 3 briefly introduces ANNs. Section 4 presents the motivations of this study as well as investigates the previous works about relationships among fingerprints and faces. Section 5 describes the evaluation methods. Section 6 presents the novelty of the proposed system including basic notations, definitions and various steps of the present method, the intelligent biometric feature prediction system (IBFPS). The experiments including numerical and graphical results of IBFPS are depicted in Section 7. Finally, the proposed work is concluded and discussed in Section 8.

2. Background of Biometric Systems

Biometric features covering physical or behavioral characteristics including fingerprint, face, ear, hand geometry, voice, retina, iris recognition, *etc.* are *peculiar* to the individual, *reliable* as far as not being transferable easily and *invariant* during the life time [1]. Typical biometric systems include enrollment, identification, verification, recognition, screening or classification processes. The steps in system tasks are as follows: biometric data acquisition, feature extraction, registration, matching, making decision and evaluation. Biometric data were obtained from people with the help of a camera-like-device for the faces and fingerprint scanner for the fingerprints, *etc.* In general, after data acquisition processes, the digital representation of the biometric data of the people were obtained in the digital platform. Feature extraction processes were applied to this digital form of the biometric features and feature sets were registered to the biometric system database. When a user wants to authenticate him/her self to the system, a fresh biometric feature was acquired, the same feature extraction algorithm is applied, and the extracted feature set is compared to the template in the database. If these feature sets of the input and the template biometric features are sufficiently similar according to the matching criteria, the user's final decision was taken and the user was authenticated at the end of the matching process [3,14].

Data acquisition, verification, identification and screening phases are the main types of biometric based systems [4]. The types are summarized as:

Type I: The biometric data acquisition phase is the first step of the other three phases. Enrollment, classification and recording of the biometric features are achieved in this phase.

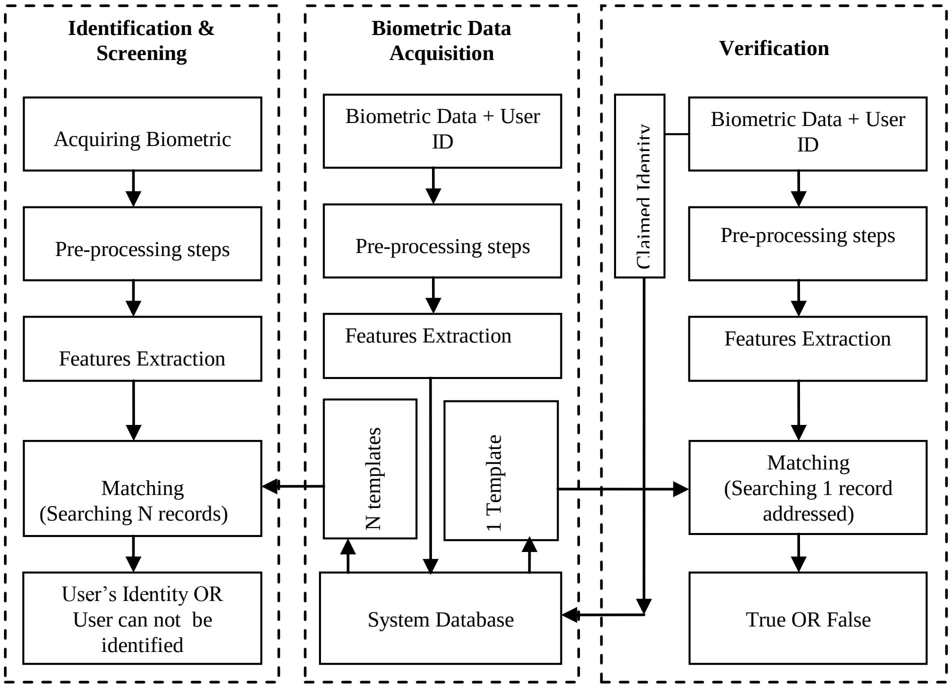
Type II: The verification phase is the most commonly used biometric system mode in the social life like person identification systems in physical access control, computer network logon or electronic data security [2,4]. In that phase an individual's identity is usually achieved via a user name, an identification number, a magnetic card, a smart card, *etc.* At the end of the verification phase, the submitted claim of the identity is either rejected or accepted [1].

Type III: The identification phase is commonly used in applications requiring high security tasks like criminal identification and police work. In that phase, the system tries to recognize an individual's identity with using just his or her biometric feature. The system fails if the person is an undefined person in the system database. In that case, the output of the system is a combination list of identities and the scores indicates the similarity among two biometric features [15]. According to some pre-defined rules about similarity measures, the system decision was produced in this phase.

Type IV: The screening phase is like the identification phase. The results of determination whether a person belongs to a watch list of identities or not is displayed in this phase. Security at airports, public events and other surveillance applications are some of the screening examples [4,16].

A typical biometric system is given in Figure 1. The processes in the system are achieved according to the arrows illustrated in the figure depending on the application status.

Figure 1. A typical biometric system.

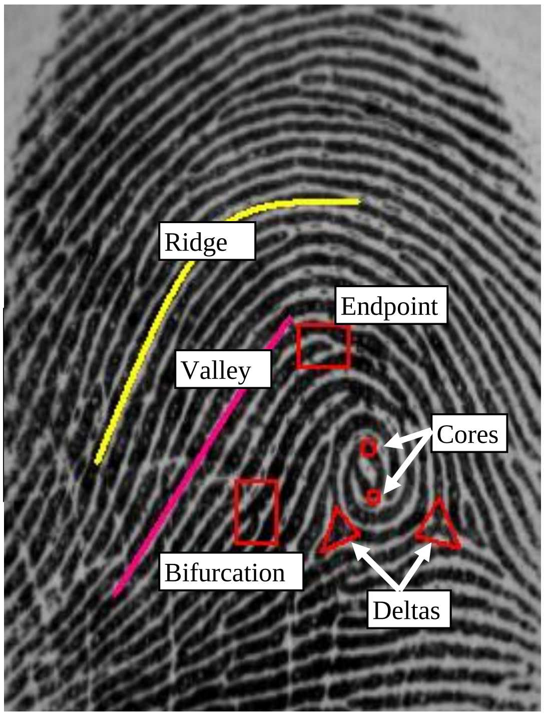


These sort of biometric recognition systems make people, systems or information safer by reducing the fraud and leading to user convenience [4]. Two of most popular biometric features used in the biometric based authentication systems are fingerprints and faces. Fingerprints based biometric systems are called AFIVSs and faces based biometric systems are called FRSs.

Fingerprints are unique patterns on the surface of the fingers. Fingerprints represent the people with high accuracy because of having natural identity throughout the life of which are not forgotten anywhere or not be lost easily. They were reliably and widely used to identify the people for a century due to its uniqueness, immutability and reliability [17].

In AFIVSs, ridge-valley structure of the fingerprint pattern, core and delta points called singular points, end points and bifurcations called minutiaes are used for identifying an individual. These structures are given in Figure 2. Many approaches to AFIVSs have been presented in the literature [1,2,15,17-30]. The AFIVSs might be broadly classified as being *minutiae-based, correlation-based* and *image-based* systems [18]. A good survey about these systems was given in the reference [1]. *The minutiae-based approaches* rely on the comparisons for similarities and differences of the local ridge attributes and their relationships to make a personal identification [19-21]. They attempt to align two sets of minutiae from two fingerprints and count the total number of matched minutiae [4]. If a minutiae and its parameters are computed relative to the singular points which are highly stable, rotation, translation and scale invariant, the minutiae will then become rotational, translational and scale invariant [15,22-24]. Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate [23,25,26]. The general methods to detect the singular points are Poincare-based [27], intersection-based [23] or filter-based [28] methods.

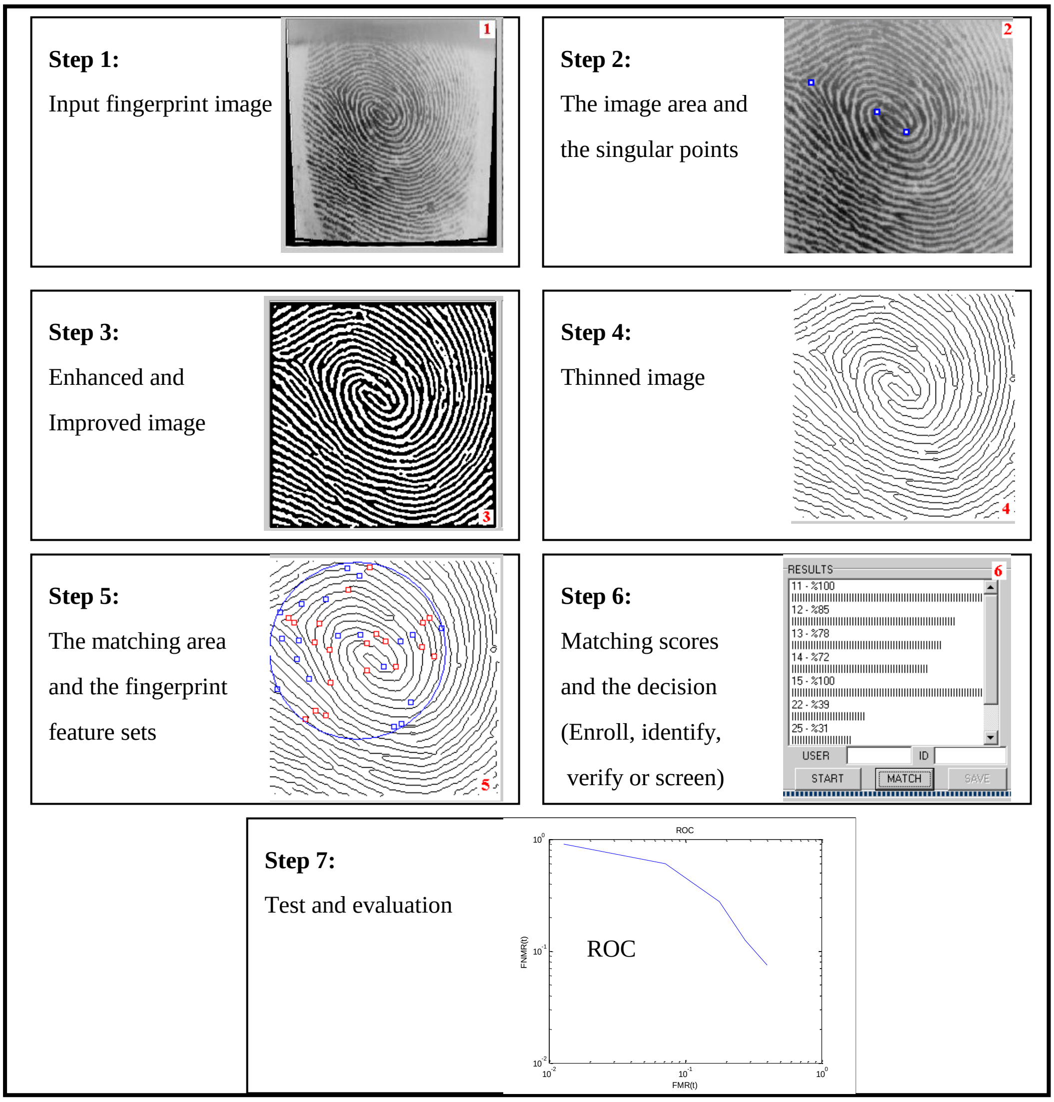
Figure 2. Ridge-valley structure and features of a fingerprint.



Main steps of the operations in the minutiae-based AFIVSs are summarized as: selecting the image area; detecting the singular points; enhancing, improving and thinning the fingerprint image; extracting the minutiae points and calculating their parameters; eliminating the false minutiae sets; properly representing the fingerprint images with their feature sets; recording the feature sets into a database; matching the feature sets; and, testing and evaluating the system [29]. The steps and their results are given in Figure 3, respectively. Although the performance of the minutiae-based techniques relies on the accuracy of all these steps, the feature extraction and the use of sophisticated matching techniques to compare two minutiae sets are often more effective on the performance.

Global patterns of the ridges and valleys are compared to determine if the two fingerprints are aligned in the correlation-based AFIVSs. The template and query fingerprint images are spatially correlated to estimate the degree of similarity between them. The performance of correlation-based techniques is affected by non-linear distortions and noises in the image. In general, it has been observed that minutiae-based techniques perform better than correlation-based ones [30]. The decision is made using the features that are directly extracted from the raw image in the image-based approaches that might be the only viable choice when image quality is too low to allow reliable minutiae extraction [18].

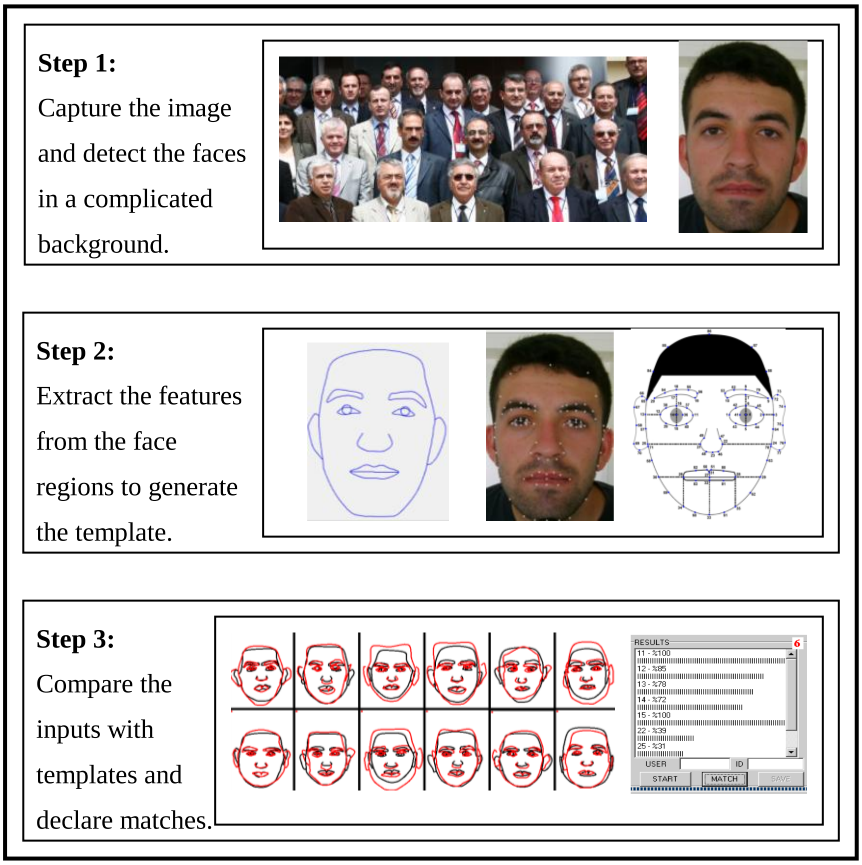
Figure 3. Main operational steps of minutiae-based AFIVSs [29].



Faces are probably the most highly accepted and user-friendly characteristics in the field of biometrics. Face recognition is an attractive and active research area with several applications ranging from static to dynamic [19]. In general, a FRS consists of three main steps covering detection of the faces in a complicated background, extraction of the features from the face regions and localization of the faces and finally recognition tasks [31]. The steps used in face processing in fingerprint to face task are illustrated in Figure 4.

Face recognition process is really complex and difficult due to numerous factors affecting the appearance of an individual's facial features such as 3D pose, facial expression, hair style, make-up, *etc.* In addition to these varying factors, lighting, background, scale, noise and face occlusion, and many other possible factors make these tasks even more challenging [31]. The most popular approaches to face recognition are based on each location and shape of the facial attributes including eyes, eyebrows, nose, lips and chin and their spatial relationships or the overall analysis of the face image representing a face as a weighted combination of a number of canonical faces [4,32]. Many effective and robust methods for the face recognition have been also proposed [2,19,31-35]. The methods are categorized in four groups as follows [34]: human knowledge of what constitutes a typical face was encoded in the knowledge-based methods. Structural features that exist even when the pose, viewpoint or lighting conditions vary to locate faces were aimed to find in the feature invariant methods. Several standard patterns of a face were used to describe the face as a whole or the facial features separately in template matching based methods. Finally, appearance-based methods operate directly on images or appearances of the face objects and process the images as two-dimensional holistic patterns.

Figure 4. Main processes of face processing for fingerprint to face task system.



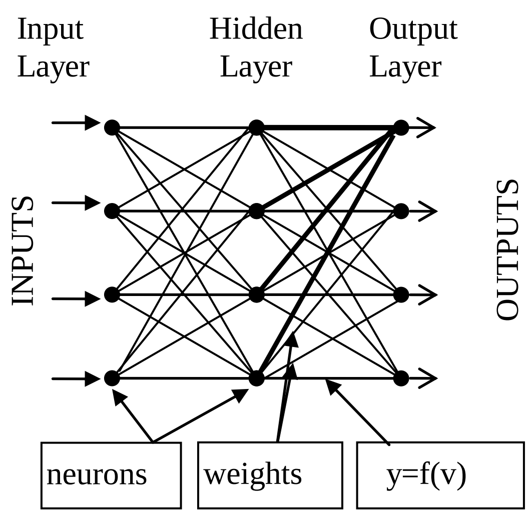
As explained earlier, processing fingerprints and faces are really difficult, complex and time consuming tasks. Many approaches, techniques and algorithms have been used for face recognition, fingerprint recognition and their sub steps. It is very clear from the explanations that dealing with generating faces from fingerprints are really more difficult tasks. Because of the tasks to be achieved in this article, faces, fingerprints, pre and post processing of them, applying many methods, implementing them in training and test procedures, analyzing them with different metrics, and representing the outputs in visual platform, *etc.* have made the prediction task more difficult.

3. Artificial Neural Networks

ANNs are biologically inspired intelligent techniques to solve many problems [36-40]. Learning, generalization, less data requirement, fast computation, ease of implementation and software and hardware availability features have made ANNs very attractive for many applications [36].There has been a growing research interest in security and recognition applications based on intelligent techniques and especially ANNs which are also very popular in biometric-based applications [5-13,29,34,35,37-40]. Multilayered perceptron (MLP) is one of the most popular ANN architectures and can be trained with various learning algorithms. Because an MLP structure can be trained by many learning algorithms, it has been successfully applied to a variety of problems in the literature [36].

The MLP structure consists of three layers: input, output and hidden layers. One or more hidden layers might be used. The neurons in the input layer can be treated as buffers and distribute input signal to the neurons in the hidden layer. The output of each neuron in the hidden layer is obtained from the sum of the multiplication of all input signals and weights that follow all these input signals. The sum can be calculated as a function. This function can be a simple threshold function, a hyperbolic tangent or a sigmoid function. The outputs of the neurons in other layers are calculated in the same way. The function can be a simple threshold function, a hyperbolic tangent or a sigmoid function. The outputs of the neurons in other layers are calculated in the same way. The weights are adapted with the help of a learning algorithm according to the errors occurring in the calculation. The errors can be computed by subtracting the ANN outputs from the desired outputs. MLPs might be trained with many different learning algorithms [36]. A general form of the MLP is given in Figure 5.

Figure 5. General Form of the MLP.



In this study, the MLP based model structure having single hidden layer was used to model the relationships and to generate the faces. The MLP models were trained with the conjugate gradient algorithm updating weight and bias values according to the conjugate gradient with Powell-Beale restarts (CGB) [41].

4. Motivation of the Proposed Approach

It is especially difficult to believe that there is a relationship between biometric features because of their characteristics such as their uniqueness. This research was difficult and challenging. As an initial step, biological and physiological evidences regarding the relationships among biometric features to support this study were investigated. The evidences and observations given below help us to believe that it is worth investigating the relationship among fingerprints and faces. These are given below:

1. It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment [42]. Physical appearances of faces and fingerprints are also a part of an individual's phenotype. In the case of fingerprints, the genes determine the general characteristics of the pattern [42]. In dermatoglyphics studies, the maximum generic difference between fingerprints has been found among individuals of different races. Unrelated persons of the same race have very little generic similarity in their fingerprints, parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in identical twins, which is the closest genetic relationship [43].
2. Some of the scientists in biometrics have focused on analyzing the similarities in fingerprint minutiae patterns in identical twin fingers [42]. They absolutely confirmed that the identical twin fingerprints have a large class correlation. In addition to this class correlation, correlation based on other generic attributes of the fingerprint such as ridge count, ridge width, ridge separation, and ridge depth was also found to be significant in identical twins [42].
3. In the case of faces, the situation is very similar with the circumstances of fingerprints. The maximum generic similarity is observed in the identical twins, which is the closest genetic relationship [43].
4. A number of studies have especially focused on analyzing the significant correlation among faces and fingerprints of identical twins [42,44-46]. The large correlation among biometrics of identical twins was repeatedly indicated in the literature by declaring that identical twins would cause vulnerability problems in security applications [47]. The similarity measure of identical twin fingerprints is reported as 95% [47]. The reasons of this high degree similarity measure were explained in some studies as follow:
    - Identical twins have exactly identical DNA except for the generally undetectable micro mutations that begin as soon as the cell starts dividing [46].
    - Fingerprints of identical twins start their development from the same DNA, so they show considerable generic similarity [48].

The similarity among biometric features of identical twins was given in Figure 6. Fingerprints of identical twins and fingerprint of another person were given in Figure 7 [46]. The high degree of similarity in fingerprints or faces of identical twins is demonstrated in Figure 8.

5. Previous Work on Relationships among Fingerprints and Faces

In the light of explanations in the previous section, identical twins have strong similarities in both fingerprints and faces. Increasing and decreasing directions of these similarities are also the same among the people. Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces. The results reported by the authors have been also experimentally shown that relationships among fingerprints and faces exist [5-13].

Figure 6. Different biometric features of identical twins [45]. (a) Retina, (b) Iris, (c) Fingerprint and (d) Palm print.

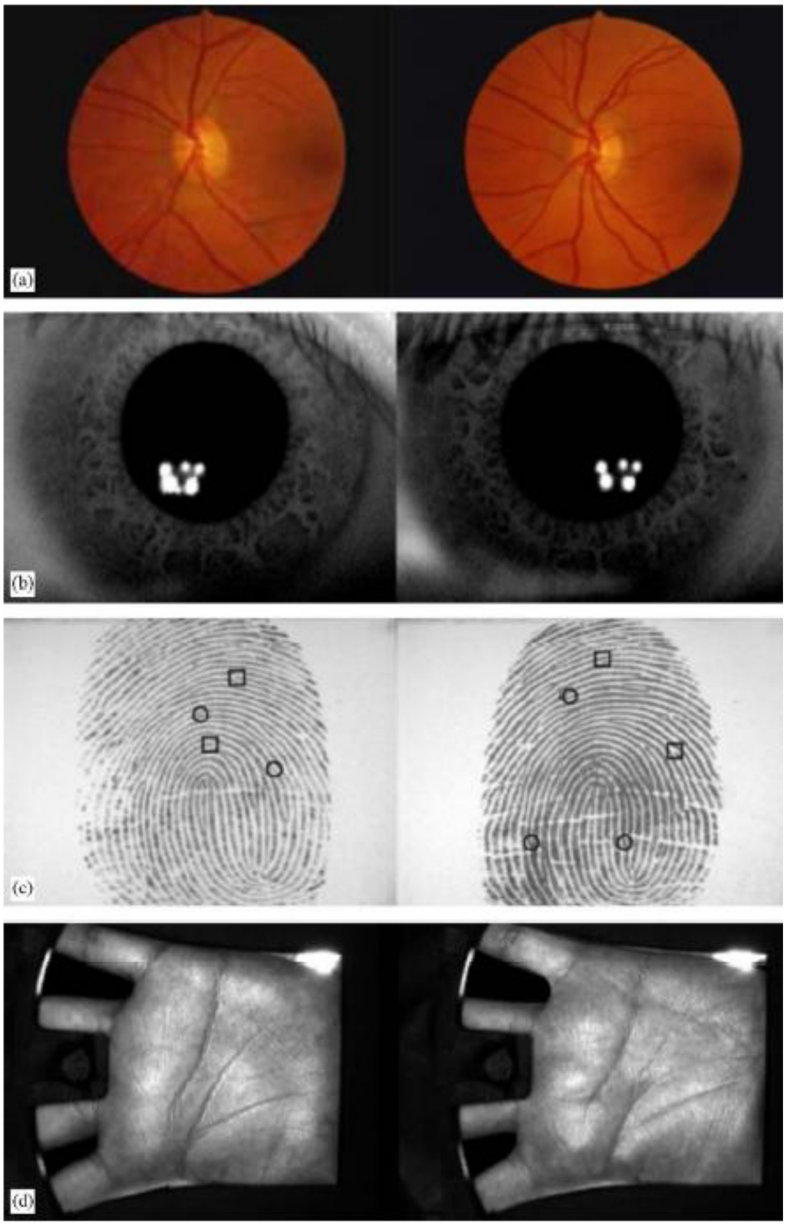


Figure 7. Fingerprints of identical twins (a, b), and fingerprint of another person (c) [46].

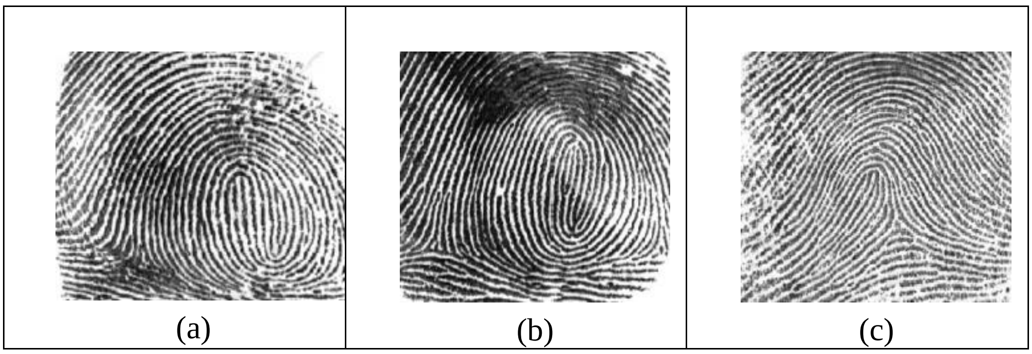
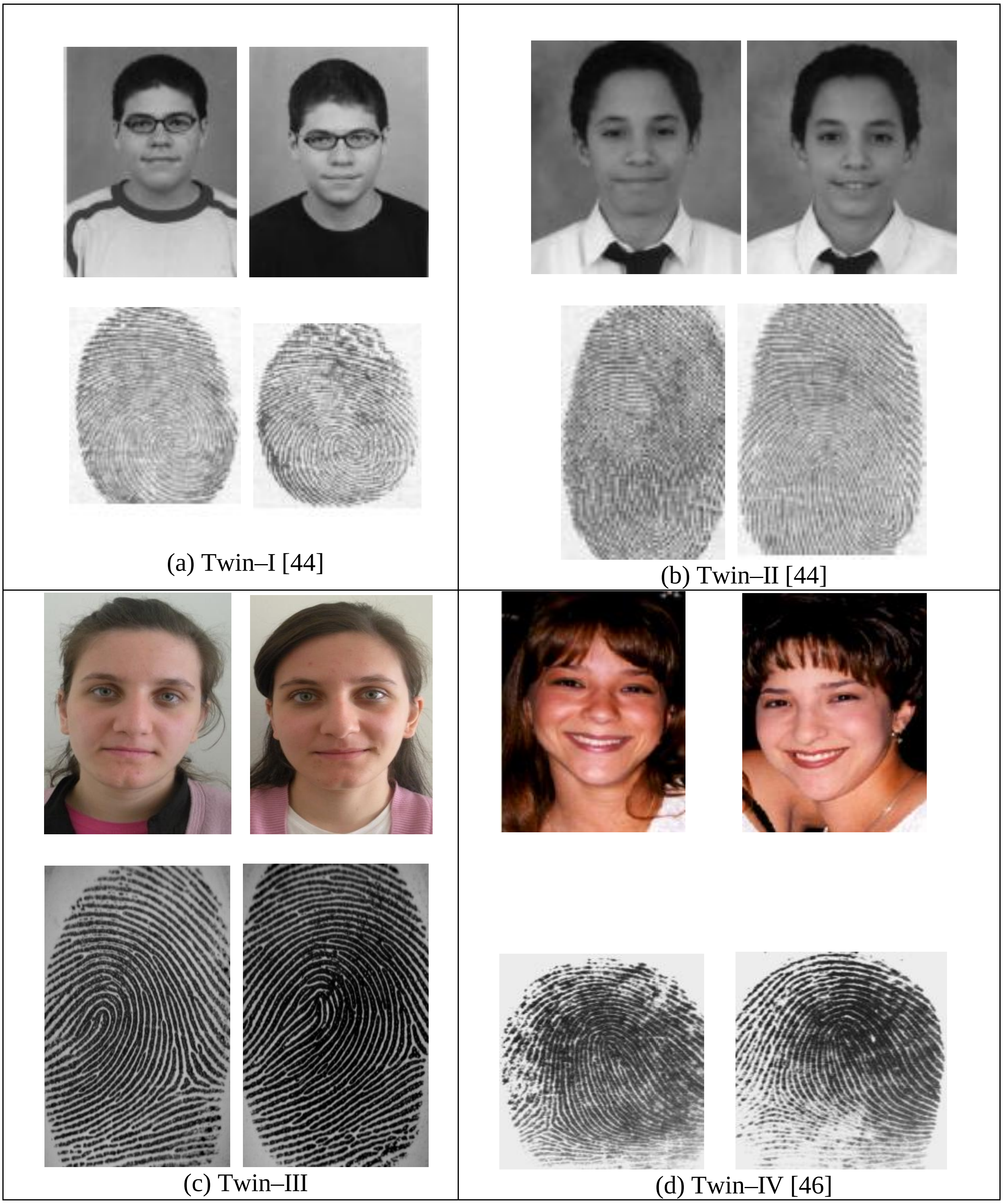


Figure 8. Fingerprints and faces for identical twins.



In the studies [5-13], relationships among fingerprint and face parts were investigated and various face parts were tried to be predicted from just fingerprints step by step from simple to complex. At the beginning of the processes, authors have tried to generate only face borders [5], only eyes [13] and face contours [6] from just fingerprints. In further steps of the process, the ANN structures were improved, trained and tested to predict static face parts [7,8,12]. After these studies, ANN structures used in predicting process were advanced owing to the experiences of the authors and more complex face parts would be generated with high accuracy [9-11]. Finally, this study introduces for the first time the most complex representation of the relationships among fingerprints and faces. The studies [5-13] presented the experimental results in different platforms such as traditional evaluation platform, numerical evaluation platform and finally a visual evaluation platform. However it should be noted that because of having limited data sets covering 120 people in those studies, 10-fold cross-validation should be applied to illustrate the performance of the system. Randomly selected train-test data sets are no longer appropriate to characterize the performance of the system. It can lead into error in evaluating the performance of the system by causing imperfect comments on the results. In 10-fold cross validation process, the database was randomly divided into 10 different data group sets covering 90% of all data set in training and the rest 10% in test data sets for each fold. The proposed system was trained and tested with these ten different training-test data sets. After ten different trainings, 10 test processes were then followed. Accuracy and performance of the ANN models for each fold were computed according to the appropriate evaluation metrics covering expanded quantitative and qualitative metrics.

The ANN structures of previous studies were designed and reconfigured with randomly selected or experimentally obtained parameters. It is well known that finding appropriate parameters depending on applications is very difficult. It takes time and suitable parameters are established with the help of trails and errors. To do it systematically, as mentioned before, this study also presents obtaining best ANN parameters like numbers of the layers, numbers of the inputs, training algorithms and activation functions with the help of Taguchi experimental design technique.

In the previous studies [5-13], performance and accuracy of the proposed model are evaluated by quantitative metrics and/or human assessment presented in a graphical form. In this paper, both the quantitative measures (*i.e.*, objective) carried out automatically by computers expanding the metrics available in the literature and the qualitative (subjective) evaluation perceived by observation were taken into account. Next section describes these quantitative and qualitative evaluation metrics.

6. Evaluation metrics

To generate more accurate face features from fingerprints without having any information about faces is successfully achieved and introduced in this study. It needs to be emphasized that evaluating results was an important, critical and difficult part in this study. There were not certain criteria to elaborate the results precisely. For doing that, the success and reliability of the proposed system having proper metrics in achieving face parts from only fingerprints must be clearly illustrated.

The traditional metrics of an ordinary biometric system like FMR-FNMR representation and ROC curve are no longer appropriate to characterize the performance of the system because of the proposed system is not an ordinary biometric-based recognition system. In this study, more test procedure and performance metrics covering combination of the quantitative and qualitative measures are introduced for better evaluations. The details of these metrics are explained in the following subsections.

6.1. Quantitative Evaluation Metrics

These metrics are briefly introduced in the following subsections.

6.1.1. FMR-FNMR Curve and The ROC Curve

FMR-FNMR and ROC curves are commonly used as evaluation metrics for biometric based recognition systems. The curves and determination procedure were detailed in [1]. The null (H_o) and alternate (H_1) hypotheses for the biometric verification problem and associated decisions according to these hypotheses were given in Table 1 and Table 2, respectively**.** If "T" is stored as a biometric template of a person and "I" is the acquired input of a biometric feature, the hypotheses for biometric verification are written for H_o:I≠T input and template do not come from the same person and H_1: I=T input and template come from the same person.

Table 1. The null and the alternate hypotheses for the biometric verification.

Formulas	Definition
H_o: I≠T	Input and template are not from the same person
H_1: I=T	Input and template are from the same person

Table 2. Decision types.

Formulas	Definition
D_o: I≠T	A person is not the same person to be claimed
D_1: I=T	A person is the same person to be claimed

In general, two types of errors are encountered in a typical biometric verification system: mistaking biometric measurements from two different fingers being the same finger (false match) and mistaking two biometric measurements for the same finger being two different fingers (false non-match). These errors are given in Table 3 for Type I and Type II, respectively. The verification involves matching T and I using a similarity measure s(T,I). If the matching score s(T,I) is less than the system threshold t, then decide D_o, else decide D_1. To evaluate the system, it must be collected the scores generated from a number of fingerprint pairs from the same finger (the distribution $p(s|H_1 = \text{true})$ of such scores is traditionally called genuine distribution), and scores generated from a number of fingerprint pairs from different fingers (the distribution $p(s|\ H_o = \text{true})$ of such scores is traditionally called impostor distribution). FMR is the probability of Type I error and could be defined as the percentage of impostor pairs whose matching score greater than or equal to t, and FNMR is the probability of Type II error and could be defined as the percentage of genuine pairs whose matching score is less than t.

Table 3. Two types of errors in a typical biometric system.

Error Type	Formulas	Definition
Type I: (FMR)	$FMR = P(D_1 \mid H_0 = true) = \int_t^1 P(s \mid H_0 = true)ds$	False match rate: (D_1 is decided when H_o is true),
Type II: (FNMR)	$FNMR = P(D_0 \mid H_1 = true) = \int_0^t P(s \mid H_1 = true)ds$	False non-match rate: (D_o is decided when H_1 is true).

Among FMR and FNMR, there is a strict tradeoff. If t is decreased to make the system more tolerant with respect to input variations and noise, then FMR increases; *vice versa*, if t is raised to make the system more secure, then FNMR increases accordingly. So the system performance was reported at all operating points (threshold, t) in ROC curves by plotting FNMR as a function of FMR [1].

6.1.2. Mean Squared Error (MSE) and Sum Squared Error (SSE)

MSE and SSE are the metrics to quantify the amount by which an estimator differs from the true value of the quantity being estimated. These metrics were used for evaluation of the performance and accuracy of the systems that were investigating the relationships among fingerprints and faces in the literature [5]-[13]. MSE is to measure the average of the square of the error. SSE is the sum of squared predicted values in a standard regression model. In general, the less the SSE, the better the model performs in its estimation. MSE and SSE were given in Equations (1) and (2), respectively. In the Equations, n is the number of the test people, O_i is the output of the system and D_i is the desired value of O_i:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(D_i - O_i\right)^2 \quad (1)$$

$$SSE = \sum_{i=1}^{n}\left(D_i - O_i\right)^2 \quad (2)$$

6.1.3. Absolute Percentage Error (APE) and Mean APE (MAPE)

APE is the measure of accuracy in a fitted time series value. It usually expresses accuracy as a percentage [50]. APE is also commonly used as an evaluation metric in the similar studies aimed to investigate among fingerprints and faces in the literature [5]-[13]. These metrics were given in Equations (3) and (4). In the equations, n is the number of the test people, O_i is the output of the system and D_i is the desired value of O_i:

$$APE = \sum_{i=1}^{n}\frac{\left|D_i - O_i\right|}{D_i} \quad (3)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|D_i - O_i\right|}{D_i} \quad (4)$$

6.1.4. Mean Absolute Error (MAE)

MAE is a quantity used to measure generations or predictions how they are close to the eventual outcomes. This metric was used in this study at first. It should be noted that, this metric was linked appropriately with the application proposed in this paper. As the name suggests, MAE is an average of the absolute errors. It is calculated average of the absolute errors per each coordinate of the feature sets of the faces in the proposed study. The formulation of MAE is given in Equation (5). In the equation, O_i is the output of the ANN, D_i is the desired value of the O_i and $e_i = D_i - O_i$:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|D_i - O_i\right| = \frac{1}{n}\sum_{i=1}^{n}\left|e_i\right| \tag{5}$$

6.2. Qualitative Evaluation Metrics

In previous studies [5-13], quantitative evaluation platforms were prepared to help the researchers determine whether the obtained results are similar to their desired values or not. In this study, in addition to that, a qualitative analysis was carried out in order to determine whether the obtained results are similar to their desired values, how much the results are close to their desired values and how accurately the system performs the task. Although the quantitative metrics indicate the system performance clearly in the numerical manner, they do not provide any information about the perceived visual quality of the results. Accordingly, a psychophysical experiment was designed and carried out below.

The aim of this qualitative analysis was to determine which quality of results the system produces imagery with the highest perceived results quality by human observers. Qualitative assessment method applied to this study was explained below.

In order to obtain an objective qualitative assessment of the results, a standard psychophysical rank-ordering paradigm [51,52] was employed to modify the paradigm for our study. Essentially, this paradigm consisted of presenting the participants with the results and asking each participant to rank order of each of those results based on their "qualities" by assigning each of the results in a numerical value. Specifically, in this study the test results for each fold were presented to the participants by asking each participant to the degree of the results in a numerical value from 1 to 5. The meanings of the numerical values are given below:

1: the results are very different from the desired values, the system failed.

2: the results are a bit similar to the desired values, but the system cannot be accepted as successful.

3: the results are similar to the desired values, the system success is average.

4: the results are very similar to the desired values, the system is above average.

5: the results are nearly the same or the same with the desired values, the system is very successful.

Before starting the experiments each participant was asked to read standardized instructions explained the task clearly. All participants were allowed to ask questions regarding the task before beginning the experiments. At the beginning of the experiments, for each trial, twelve results for each 10-fold cross validation were simultaneously displayed. At the end of each checking process, he or she gives a mark for the test results of each fold. At the end of this part of the evaluation, each participant checks all test results of the 10-fold cross validation containing 120 test people and gives a mark for each fold to evaluate the results if face prediction is successfully achieved or not.

7. The Proposed System: Intelligent Biometric Feature Prediction System (IBFPS)

In order to achieve the task of prediction, a proposed system called IBFPS was developed and implemented. The new approach successfully generates total face features containing all of the face parts including eyebrows, eyes, nose, mouth and face contours including face border and ears from only fingerprints without having any information about faces in this study. In addition, the relationships among Fs&Fs are also analyzed and discussed in more details with the help of different evaluations criteria.

Assume that this relationship among faces and fingerprints can be mathematically represented as:

$$y = H(x) \tag{6}$$

where y is a vector indicating the feature set of the face model and its parameters achieved from a person, x is a vector representing the feature set of the fingerprint acquired from the same person, $H(.)$ is a highly nonlinear system approximating y onto x. In this study, $H(.)$ is approximated to a model to generate the relationship among Fs&Fs with the help of ANN models.

The proposed system is based on MLP-ANN model having the best parameters with the help of Taguchi experimental design technique [53-55]. MLPs were trained with the binary input vectors and the corresponding output vectors with different parameter levels based on Mean Square Errors (MSEs) and Absolute Percentage Errors (APEs).

In order to determine the best parameters of MLP-ANN structure, L-16 ($8^{**}1$ $2^{**}3$) Taguchi experiment is designed. Taguchi design factors and factor levels were given in Table 4. Training algorithms, the numbers of layers, the numbers of inputs and the transfer functions were main Taguchi design factors and 8, 2, 2 and 2 to be considered as factor levels, respectively.

MLP-ANN training algorithms considered and used in this work were Powell-Beale conjugate gradient back propagation (CGB), Fletcher-Powell conjugate gradient (CGF), Polak-Ribiere conjugate gradient (CGP), Gradient Descent (GD), Gradient Descent with adaptive learning coefficients (GDA), One Step Secant (OSS), GDA with momentum and adaptive learning coefficients (GDAM) and scaled conjugate gradient (SCG) [56].

In this study, the numbers of layers were set to 3 and 4, the numbers of inputs were 200 and 300. Hyperbolic Tangent (HT) and Sigmoid Function (SF) activation functions were considered and used in MLP-ANN structures.

In Taguchi design, best parameters of MLP-ANNs were determined according to MSEs. Main effect plots were taken into considerations while analyzing the effects of parameters on the response factor. These plots might help to understand and to compare the changes in the level means and to indicate the influence of effective factors more precisely. According to these plots, training algorithms had the largest main effect on MSE. The numbers of layers in MLP-ANN structure, and transfer functions were also considerably effective. MSEs were not mainly affected by the numbers of inputs. Finally it can be clearly said that considering the main effect plots, MSEs will get smaller if the parameter settings given in Table 5 were followed.

Table 4. Taguchi design factors and factor levels.

Taguchi Design		LEVELS							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
DESIGN FACTORS	Training Algorithms	CGB	CGF	CGP	GD	GDA	OSS	GDAM	SCG
	Number of Layers	3	4						
	Number of Inputs	200	300						
	Transfer Functions	HT	SF						

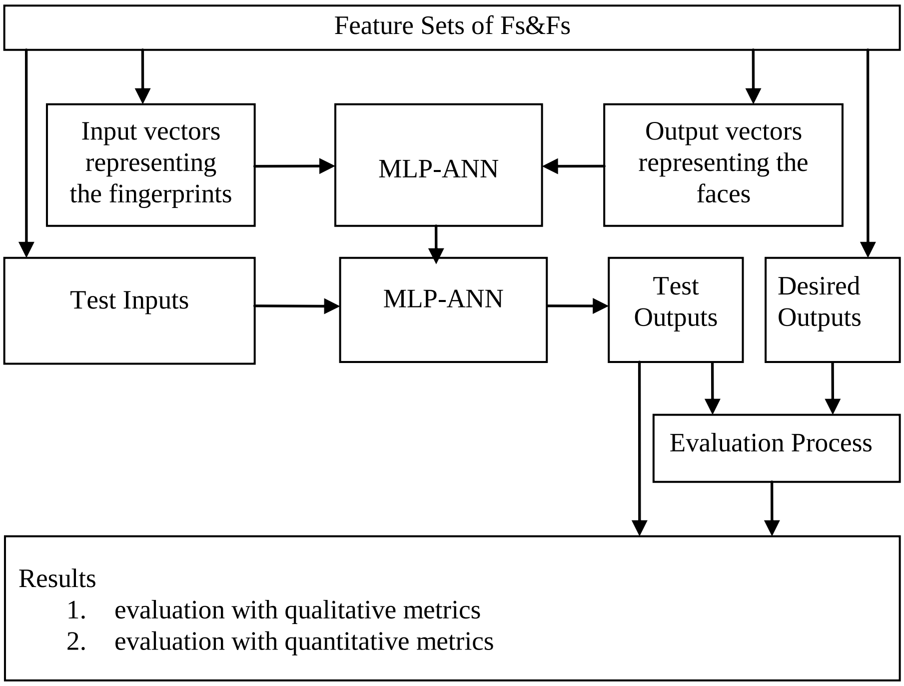
Table 5. Results for ANN Parameter Analysis.

Factors	Parameter Settings		
	Means	SR	Optimum Design
Training Algorithms	CGB	CGB	CGB
Numbers of Layers	3	3	3
Numbers of Inputs	300	300	300
Transfer Functions	SF	SF	SF

After the ANN structure and its training parameters were determined to achieve accurate solutions, the training processes were started with applying the fingerprint and face feature sets of the people to the system as inputs and outputs, respectively. The sizes of input and output vectors were also 300 and 176, respectively. The system achieves the training processes with these feature sets according to the learning algorithm and the ANN parameters which were obtained from Taguchi design method. Even if the feature sets of Fs&Fs were required in training, only fingerprint feature sets were used in test. It should be emphasized that these fingerprints used in test were totally unknown biometric data to the system. The outputs of the system for the unknown test data indicate the accuracy of the system. The success and reliability of the system must be clearly shown by evaluating the ANN outputs against the proper metrics in achieving face parts from fingerprints. The block diagram of the MLP-ANN used in this work is given in Figure 9.

According to the best parameters obtained from Taguchi method, the MLP-ANN models were trained with a conjugate gradient algorithm that updates weight and bias values according to the conjugate gradient back propagation with Powell-Beale restarts (CGB). The CGB is a network training algorithm that updates weight and bias values according to the CGB algorithm [56]. Conjugate gradient algorithms (CGAs) execute very effective search in the conjugate gradient direction. Generally, a learning rate is used to determine the length of the step size. For all CGAs, the search direction will be periodically reset to the negative of the gradient. The standard reset point occurs when the number of iterations is equal to the number of network parameters (weights and biases), but there are other reset methods that can improve the efficiency of training [57]. One such reset method was proposed by Powell [41], based on an earlier version proposed by Beale [58].

Figure 9. The block diagram of the MLP NN structure.



In principle, feed forward neural networks for non-linear system identification can use all CGAs. In the first iteration, the CGAs start out by searching in the steepest descent direction that was given in Equation (7):

$$p_0 = -g_0 \tag{7}$$

In the equation, p_o and g_o are the search vector and gradient, respectively. Consider x_k is the estimate of the minimum at the start of the k-th iteration. The k-th iteration then consists of the computation of search vector p_k from which new estimate x_{k+1} is obtained. It is given in Equation (8):

$$x_{k+1} = x_k + \alpha_k p_k \tag{8}$$

In the equation, α_k is previous knowledge based upon the theory of the method or obtained by linear search. The next search direction is determined so that it is conjugate to previous search directions. Combining the new steepest descent direction with the previous search direction is the general way for determining the new search direction. It is given in Equation (9). In the equation, β_k is a positive scalar and the various versions of gradient are distinguished by the manner constant β_k is computed [59]:

$$p_k = -g_k + \beta_k p_{k-1} \tag{9}$$

Periodically resetting the search direction to the negative of the gradient improves the CGAs. Since Powell-Beale procedure is ineffective, a restarting method that does not abandon the second derivative information is needed. According to Powell-Beale technique it will restart if there is very little orthogonality left between the current gradient and the previous gradient. This is tested with the inequality given in Equation (10). If this condition is satisfied, the search direction is reset to the negative of the gradient:

$$\left|g_{k-1}^T g_k\right| \geq 0.2\left\|g_k\right\|^2 \tag{10}$$

The inputs and outputs of the system were digital representations of fingerprints and faces of the people, respectively. The feature vectors of the fingerprints obtained from a commercially available software development kit contain the local and global feature sets of the fingerprints including singularities, minutiae points and their parameters [60]. Detailed explanation of the feature extracting algorithms, extensive information of fingerprint feature sets and their storage format were given in the reference [60]. These discriminative data represent the people with high accuracy. The outputs were the feature vectors of the faces obtained from a feature-based face feature extraction algorithm that was borrowed from Cox *et al.* [61] and fundamentally modified and adapted to this application. Increasing the number of the reference points 35 to 88 helped to represent the faces more accurately and sensitively. Face feature sets were also shaped from Cartesian coordinates of the face model reference points not distances or average measures as given in the reference [61]. It was also observed that feature sets contain enough information about faces for getting them again with high accuracy. The face reference points on the template, on the face image of a person from our database and re-construction of the face model from the reference points were given in Figure 10.

Figure 10. Face reference points a) on the template, b) on a real face image from the database, c) re-construction of the face model from the reference points.

(a) (b) (c)

A flexible design environment for the face model re-construction converting the ANN outputs and/or the desired outputs to visual face models was also included in the software developed. Indeed, it basically transformed the reference points of the face models to the lines. The software is capable of plotting the results of actual and/or calculated values of the same face in the same platform or in different platforms. It also illustrates the ANN results on the real face images. So, the face model re-construction handles an important task for the system by creating two different visual evaluation platforms. This re-construction process enables users to achieve the qualitative evaluation processes easily, efficiently and automatically with the support of the developed useful graphical interface.

At the beginning of the experiment, an enrollment procedure was followed for collecting the biometric data from the people. This enrollment procedure helps to store fingerprint and face biometrics of individuals into the biometric system database. During this process a real multimodal database belonging to 120 persons was established. Ten fingerprints of each individual were scanned with a fingerprint scanner, and a 10 face image having different angles were also taken from the people using a digital camera. A set of examples including fingerprints and faces of an individual were given in Figure 11 and Figure 12, respectively. Only one frontal face image and one fingerprint belonging to the right hand index finger for each person were used in this study.

Figure 11. Ten fingerprint images of an individual from our database (from "1" to "10", from the left to the right, respectively).

Figure 12. Face images captured from different angles from an individual.

The software developed achieves all the tasks of the system from the enrollment step to evaluation step completely. It is expected that generating faces from fingerprints without having any priori knowledge about faces will find considerable attention in science and technology of biometrics, security and industrial applications.

As mentioned earlier, evaluating this system is very critical from the point of being a pioneering study claiming to generate the facial parts including the inner face parts with eyebrows and face contour with ears from only fingerprints. So, the success and reliability of the system must be clearly depicted. In that case, test processes in this article were mainly divided into two main parts: qualitative and quantitative evaluation platforms.

8. Experimental Results

In order to achieve the experiments effectively, automatically and easily, a software platform covering Figures 3, 4 and 5 was developed.

In order to generate faces from only fingerprints, the following experiments were performed as:

1. Read fingerprints and faces from database
2. Obtain the feature sets of fingerprints and faces.
3. Establish a network configuration for training
4. Find optimum parameters with the help of Taguchi method.
5. Train the network with selected parameters.
6. Save the results for further uses.
7. Test the system against to the proper evaluation metrics.
8. Test the system performance based on 10-fold cross validation technique.
9. Investigate whether the quantitative (objective) evaluation results are consistent with qualitative (subjective) evaluations based on human perceptual assessment.

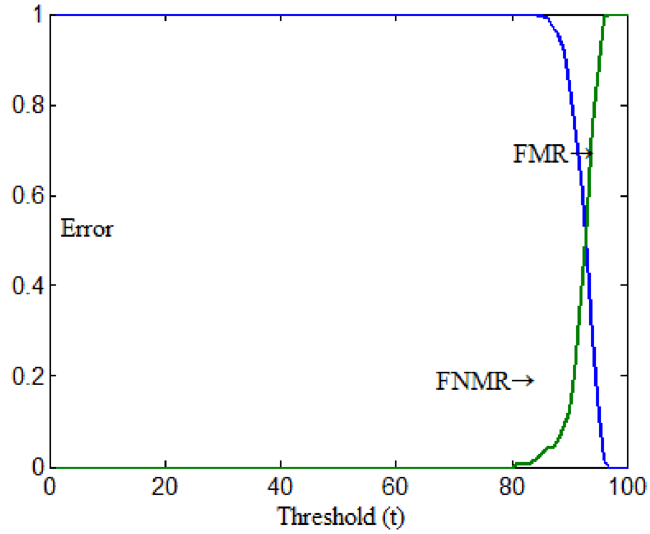
Previous experiments on predicting faces from fingerprints [5-13] have shown that the relationship between fingerprints and faces can be also achieved with high accuracy. In the current experiments, an automatic and intelligent system based on artificial neural network is designed to generate the faces of people from their fingerprints only. The proposed study has some advantages on the previous studies in the literature. These features are given below as:

1. All face parts including eyebrows, eyes, nose, mouth, face border and ears were successfully predicted in this study for the first time.
2. The optimal parameters of ANN model parameters were determined with the help of Taguchi experimental design technique.
3. Qualitative evaluation procedure was followed in addition to the quantitative evaluation procedure with some extra quantitative metrics.
4. 10-fold cross validation technique was applied to analyze and to evaluate the performance and the accuracy of the system more precisely.

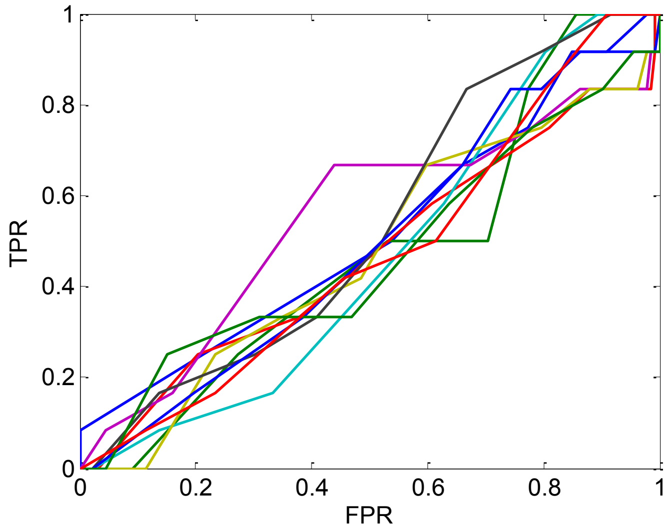
Producing the face models as close as possible to the real one is the most critical part of the system in this study. In order to evaluate the performance of the developed system effectively, test experiments were mainly focused on two qualitative and quantitative evaluation platforms: a 10-fold cross-validation method was followed, as mentioned earlier. The results of the system were tested against to these evaluation metrics.

FMR&FNMR and ROC curve representations were also given in Figure 13. In the figure, ROC curves were plotted for each fold separately, but the FMR&FNMR representation curve was drawn using only average value of all folds for better comparison.

Figure 13. Test results for different representations (TPR: True Positive Rate, FPR: False Positive Rate). (a) FMR&FNMR representation; (b) ROC curves.



(a)

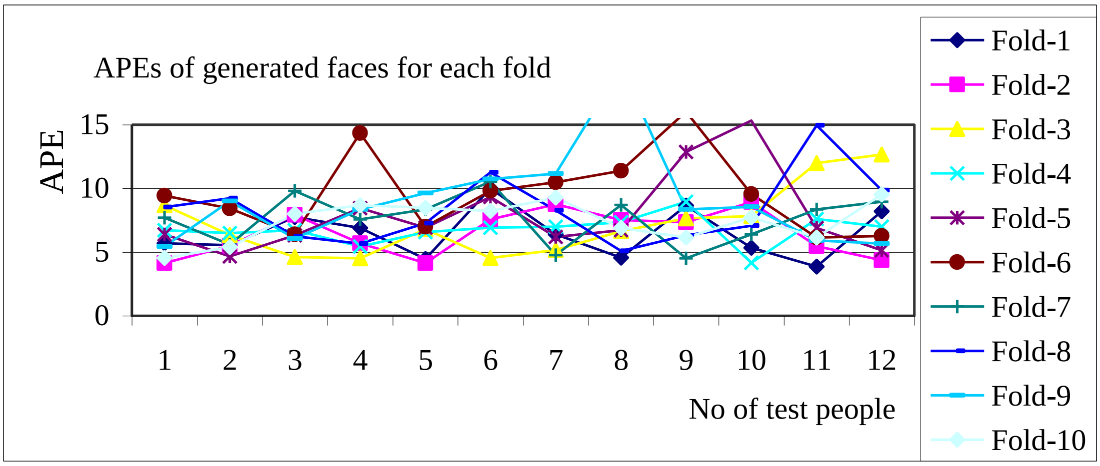


(b)

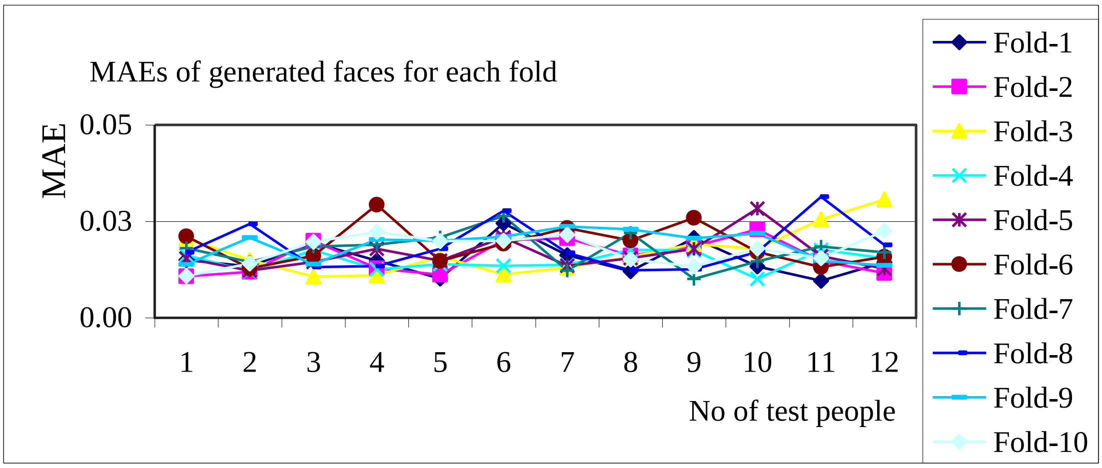
As can be seen in Figure 13, the proposed system performs the tasks with high similarity measures to the desired values. According to the numerical results given in Table 6, the proposed system was found also very successful.

The APE, MAE and MAPE values belonging to all test results for each fold of 10-fold cross validation were demonstrated in Figure 14. Averages of all APEs, MAEs and MAPEs were given in Figure 15.

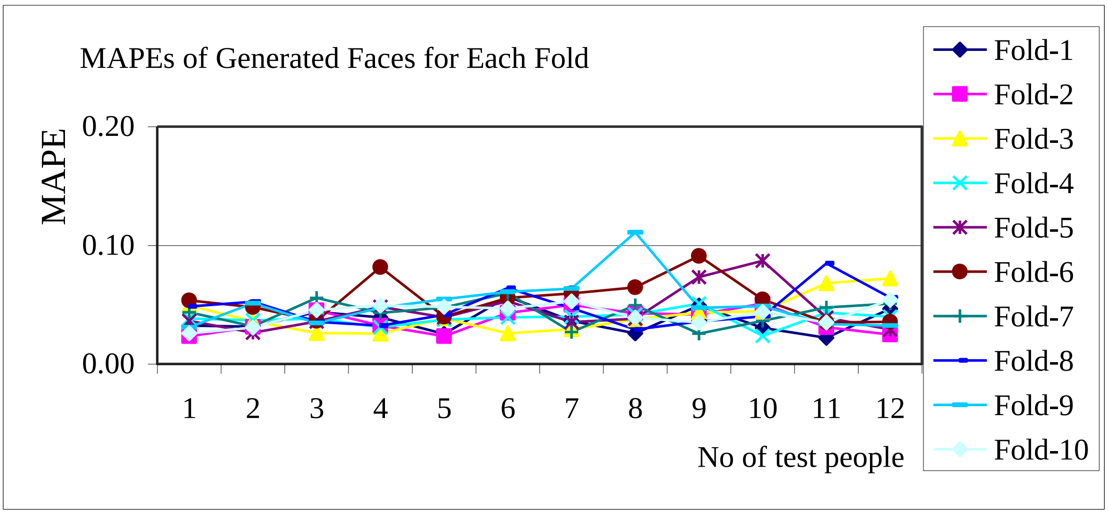
Figure 14. Results for APEs, MAEs and MAPEs for each fold. (a) APEs for generated faces for each fold; (b) MAEs for generated faces for each fold; (c) MAPEs for generated faces for each fold.



(a)

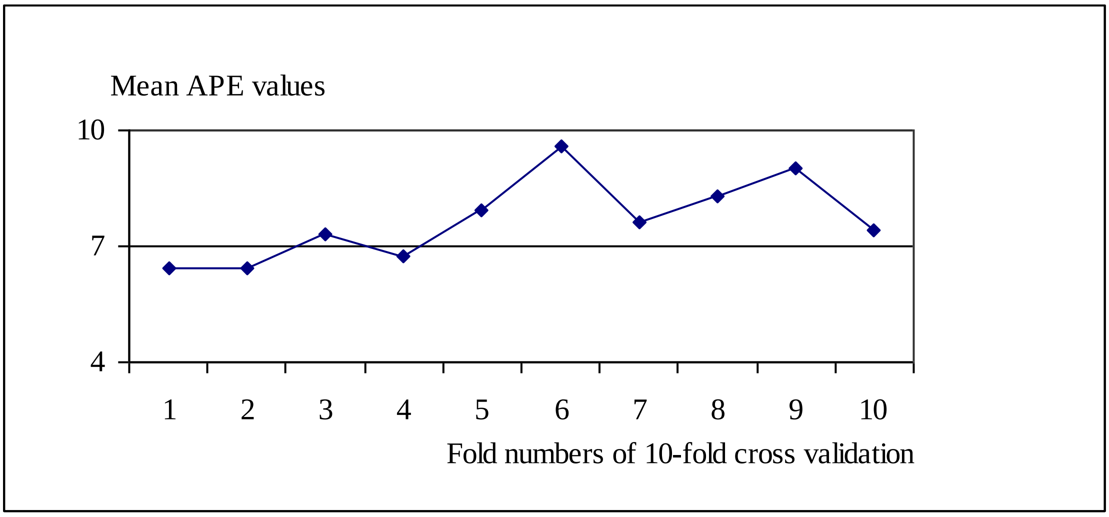


(b)

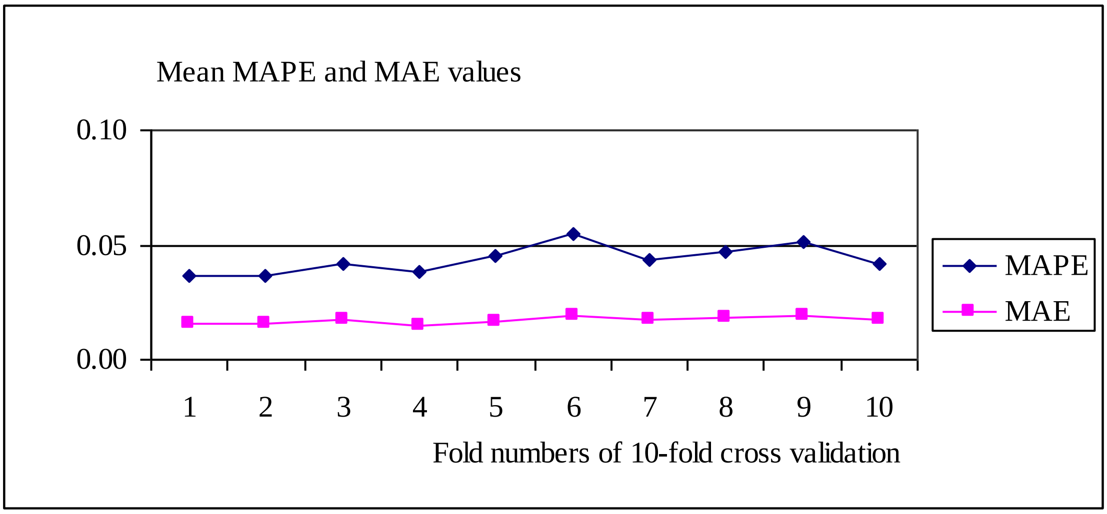


(c)

Figure 15 Averages of APEs, MAEs and MAPEs. (a) Averages of APE values of generated faces for each fold; (b) Averages of MAPE and MAE values of generated faces for each fold.



(a)



(b)

Table 6. Numerical results for comparison.

	Maximum	Mean	Minimum
APE	9.60953	7.68515	6.44791
MSE	0.00067	0.00038	0.00053
SSE	1.40740	0.79380	1.12700
MAE	0.01905	0.01718	0.01482
MAPE	0.05460	0.04367	0.03664

For more realistic and comprehensive evaluation, all test results at each fold were illustrated in Figure 16 with the desired values as used in the qualitative assessment method. Dark and light lines in the figure represent the desired and the generated face features, respectively. The number of rank orders in 10-fold cross validation with 20 participants as the results of the qualitative assessment method was given in Table 7.

Figure 16. Results for 10 different test data sets.

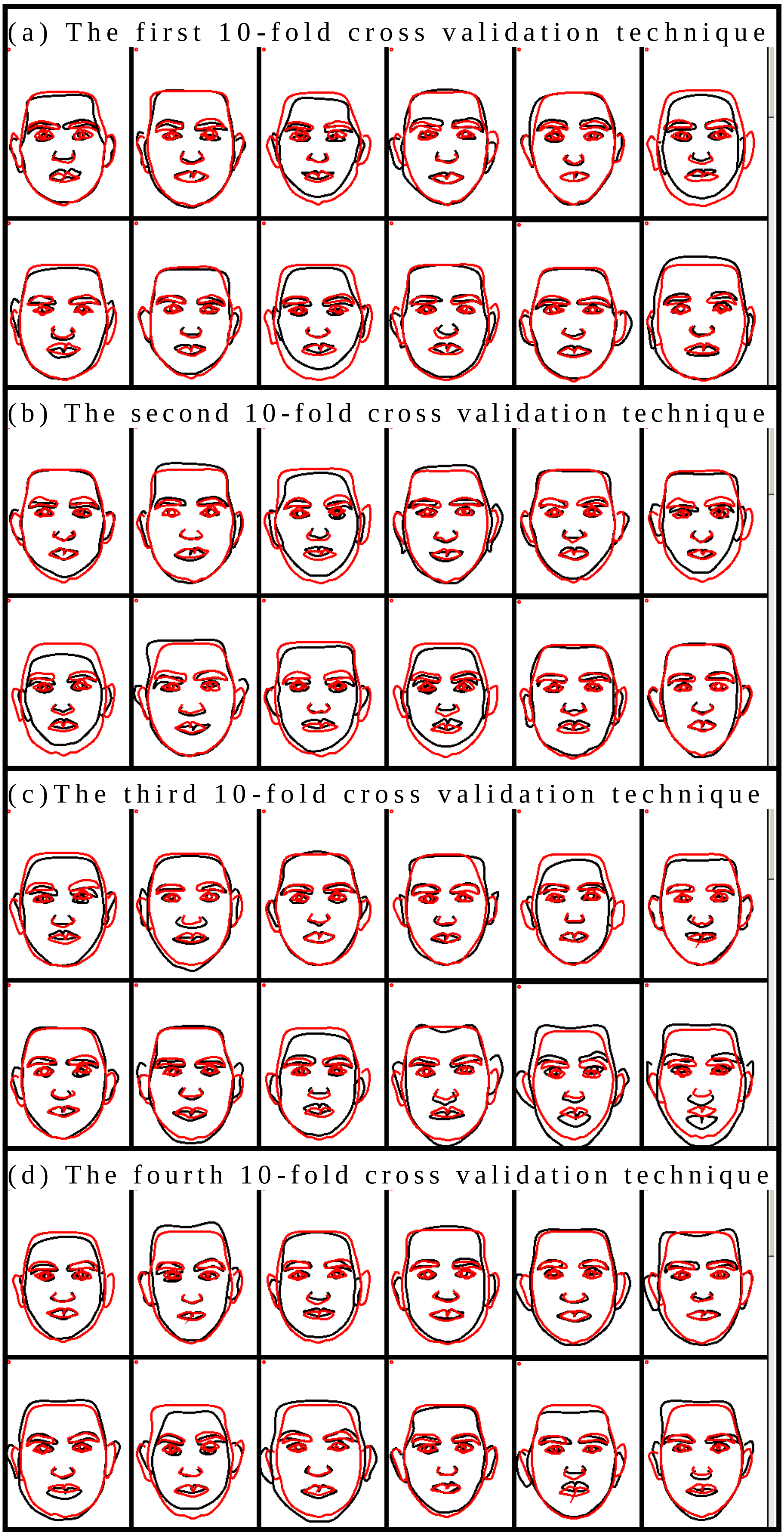


Figure 16. *Cont.*

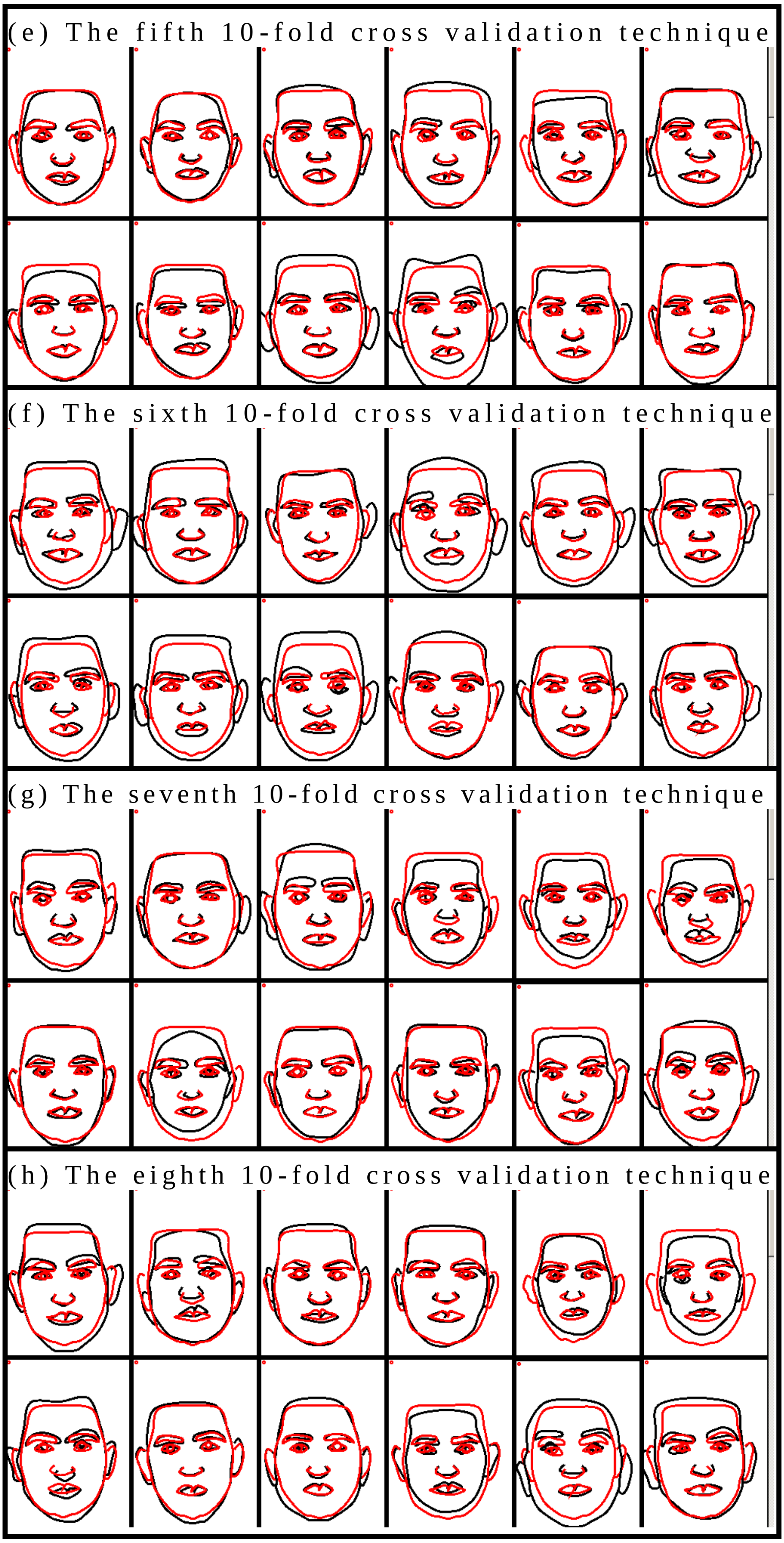


Figure 16. *Cont.*

Table 7. Number of rank orders in 10-fold cross validation with 20 participants.

No of 10-folds	Rank Levels				
	1	**2**	**3**	**4**	**5**
The first	0	0	0	4	16
The second	0	0	2	11	7
The third	0	0	6	4	10
The fourth	0	1	3	5	11
The fifth	0	1	2	8	9
The sixth	0	3	5	10	2
The seventh	0	0	2	7	11
The eighth	0	0	4	6	10
The ninth	0	0	5	10	5
The tenth	0	0	0	6	14
Total	0	5	29	71	95

All observers who participated in our qualitative assessment method had normal (20/20) or corrected to normal acuity, normal color vision, and no history of ocular pathologies. In the qualitative assessment method each of the participants has assigned a numerical value of 1, 2, 3, 4 or 5 for all results of the each fold. Thus, within each condition, the system results were assigned 200 values (ten values per participant). In order to carry out a meaningful quantitative analysis, the rank frequency, that is, the number of times was assigned a rank value (*i.e.*, the number of all the ones, twos, threes, fours and fives for the results), was taken as the operational definition of perceived result quality for each fold. For each condition, the rank frequency was summed across the 10-folds, which resulted in the summed rank frequency (refer to line "Sum" in Table 7). From Table 7, it is clear that the proposed system was assigned the highest number of fives for all folds of 10-fold cross validation technique. According to the means of qualitative assessment method, the proposed system produced high quality results that were perceived to have the highest marks. Comparison for the folds of 10-fold cross validation technique can be also achieved using Table 7. According to Table 7, the first fold of the system was perceived to have the highest marks, tenth fold of the system produced imagery that was assigned the second highest number of fives (*i.e.*, essentially perceived as 'second best'); and the seventh fold of the system produced imagery that was assigned the third highest number of fives (*i.e.*, essentially perceived as 'third best'). For each condition the rank frequency was summed across the all folds of 10-fold cross validation technique.

Total value of the table indicates the sum of the marks for the all test results. It actually shows the overall system performance from point of the subjective manner. According to the total value, 47.5% of the participant gave 5, it means that they thought that "the results are nearly the same with the desired values, the system is"; 35.5% of the participant gave 4, it means they thought "the results are very similar to the desired values, the system is successful", 14.5% of the participant gave 3, it also means that they thought "the results are similar to the desired values, the system success is average" and 2.5% of the participant gave 2, it means they thought "the results are a bit similar to the desired values, but the system cannot be accepted successful". None of the participant gave 1, so no of them thought that the system is failed.

All obtained results from the two different evaluation platforms for each fold of 10-fold cross-validation technique have strongly demonstrated and clearly confirmed that there are close relationship among faces and fingerprints. Based on the results reported in this article in various forms, it can be clearly and confidently to declared that the proposed face model generation system is very successful in achieving face parts from only fingerprints. The system presented in this paper is a complete system combining all the other recent works introduced in [5-13], and it provides more complex and distinguished solution for generating the face parts. To the best of our knowledge, investigating relationships among fingerprints and face features including the all face parts has not been studied in the literature so far. Also it is the first study that was evaluated with 10-fold cross validation technique with qualitative evaluation metrics in addition to the quantitative evaluation metrics. Taguchi experimental design technique was also used to obtain best ANN parameters for better performance. Extensive experimental results have shown once more that the proposed system yields superior performance and it is capable of efficiently generating the face masks from only fingerprints.

9. Conclusions and Future Work

Predicting complete face features with high accuracy just from fingerprints is the principal objective of this paper. In this study a novel approach was developed, used and introduced to successfully achieve this aim. In the proposed study, the relationships among fingerprint and face biometrics were established and an unknown biometric feature was also predicted with high accuracy from a known biometric feature. The results of the two main validation tests proved that the proposed system is very successful in automatically generating the faces from only fingerprints. This study is an improved version of our earlier studies.

In the future research, investigations will be conducted to enhance the face generation process. In addition, a larger multi-modal database with international participants including Fs&Fs will be collected to investigate the proposed approach. Even if an unknown biometric feature can be achieved from a known biometric feature, the achieved feature cannot represent faces in real time face pictures. This initial study might help to lead to create new concepts, research areas, and especially new applications in the field of biometrics.

Comparing with the results given in the literature determining the best parameter settings by Taguchi experimental design technique has improved the results significantly. In addition, it should be noted that predicting more face parts from fingerprints reduced the prediction performance of the system.

For a more objective comparison, the performance and accuracy of the system have been evaluated with 10-fold cross validation technique using qualitative evaluation metrics in addition to the expanded quantitative evaluation metrics. Consequently, the results were presented on the basis of the combination of these objective and subjective metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.

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AN INTELLIGENT AND AUTOMATIC FACE SHAPE PREDICTION SYSTEM FROM FINGERPRINTS

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ABSTRACT—This paper presents an intelligent system for generating face shapes from only fingerprints without knowing any information about faces. The proposed system based on artificial neural network has got a number of modules including two biometric data acquisition modules, two feature extraction modules, an artificial neural network module, a face re-construction module and a test & evaluation module. Experimental results have shown that the faces can be successfully generated from only fingerprints. Although the proposed system is an initial study, the performance of the system is very promising for the future developments.

Key Words: Intelligent systems, biometrics, artificial neural networks.

1. INTRODUCTION

Biometrics is a well known technology and deeply studied research field especially to support reliable personal identification systems. Recently, most of the works in this area have focused on improving the accuracy and processing time of the biometric-based systems. For achieve this improvement more effective, fast and robust techniques have been developed [1]. Obtaining a biometric feature of a person from another biometric feature of the same person is a challenging idea and it is a useful transformation for many applications. There has been no study on investigating relationships among the biometric features or obtaining one feature from another except the authors have recently reported in the articles [2]-[10] for the first time. The authors proposed novel approaches for generating the face borders [2], the face contours including face border and ears [3], the face models including eyebrows, eyes and mouth [4], the inner face parts including eyes, nose and mouth [5], the face parts including eyes, nose, mouth and ears [6], the face models including eyes, nose, mouth, ears and face border [7], the face parts including eyebrows, eyes, nose, mouth and ears [8], only eyes [9] and the face parts including eyebrows, eyes and nose [10] from only fingerprints without any need for face information or images. The results in the articles have clearly demonstrated that an unknown biometric feature can be achieved from a known biometric feature.

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Some biological and physiological evidences were motivated to us to investigate the relationships among fingerprints and faces. These evidences can be explained as follows: It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment [11]. Physical appearances of faces and fingerprints are also a part of an individual's phenotype. In dermatoglyphics studies, the maximum generic difference in fingerprints has been found among individuals of different races [11]. Unrelated people of the same race have very little generic similarity in their fingerprints; parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in the identical twins, which is the closest genetic relationship [12]. This similarity distribution is very similar for faces of the people. The general characteristics of fingerprints and faces were determined by the genes [11]. These truths have indicated that there could be some relationships among biometrics. In order to investigate and support this assumption an intelligent face prediction system from only fingerprints has been developed and introduced in this study.

2. OVERVIEW OF BIOMETRICS

A biometric system operates its task by getting biometric data from a person, extracting a feature set from the acquired data and comparing this feature set against the template feature sets in the database [13]. The most used biometric systems are Automatic Fingerprint Identification Systems (AFISs) and Automatic Face Recognition Systems (AFRSs). Good surveys about these techniques were given in [1] and [14], [15], respectively. This study focuses on fingerprints and faces (Fs&Fs). To acquire feature sets of Fs&Fs in the literature, feature-based approaches have been mostly used. In the feature-based AFISs, two important attributes including end points and bifurcations were used [1]. Feature-based AFRSs mainly consist of three steps. These steps cover detection and localization of the faces, feature extraction and finally recognition tasks [16]. Both fingerprint and face recognition processes are really complex and difficult tasks [1], [14] and [16]. Recently, multi-modal biometric systems (MMBS) have gained acceptance among designers due to their performance superiority over the uni-modal systems that have some limitations about accuracy, processing time and vulnerability to spoofing [15]. Detailed information about MMBSs can be found in [13] and [17].

3. ARTIFICIAL NEURAL NETWORKS

Artificial Neural Networks (ANNs) have been applied to solve many problems [1], [14], [18]-[20]. Learning, generalization, less data requirement and fast computation features have made ANNs very attractive for applications [18]. These fascinating features have also made them popular in biometrics [1]-[10], [14], [19] and [20]. Multilayered perceptron (MLP) structure was used in this study. The MLP consists of three layers: Input, output and hidden layers. The neurons in the input layer can be treated as buffers and distribute x_i input signal to the neurons in the hidden layer. The output of the each neuron y_j in the hidden layer is obtained from sum of the multiplication of all input signals x_i and weights w_{ji} that follow all these input signals. The outputs of the neurons in other layers are calculated in the same way. The weights are adapted with the help of a learning algorithm according to the error occurring in the calculation. The error can be calculated by subtracting the ANN output from the desired output [18]. There have been many learning algorithms to train ANNs. The scaled conjugate gradient (SCG) algorithm is one of them. It is based on conjugate directions and adjusts the weights of ANNs [23].

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4. AUTOMATIC FACE SHAPE PREDICTION SYSTEM FROM FINGERPRINTS

Unlike to the previous studies [2]-[10], the proposed ANN based intelligent system generates the face shape including *eyes, mouth* and *face border* of a person from only one fingerprint of the same person. The architecture of the developed Fingerprint to Face Shape Generation System (FP2FSPS) covering main modules is given in Figure 1. Implementation steps of the FP2FSPS to establish a relationship among fingerprints and faces (Fs&Fs) can be mentioned as follows:

1. A real multi-modal database was established from Fs&Fs.
2. Feature sets of Fs&Fs were obtained.
3. Training and test data sets were established.
4. Suitable ANN structure and its optimal parameters were determined. The ANN structure is finally established.
5. ANN based FP2FSPS was trained to generate face shapes more realistically until achieving certain accuracy in learning.
6. In order to test and evaluate the accuracy of the FP2FSPS, the test results were compared against to a variety of state-of-the-art methods [1].

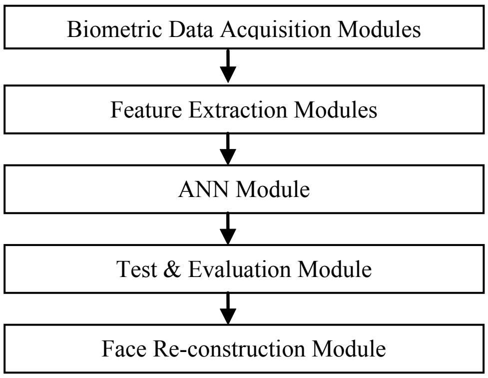

Figure 1. Architecture of the FP2FSPS

Biometric data acquisition modules help to store biometric data of individuals into the system database. A real multi-modal database that includes Fs&Fs belonging to 120 people was established. Only a frontal face image and a fingerprint that was index finger of the right hand were used in this study. An example of biometric feature set in the database is given in Figure 2.

Figure 2. An example for F&F set in the multimodal database

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The feature extraction modules extract the discriminative feature sets from the acquired biometric data. Fingerprint feature sets were computed using a SDK developed by Neurotechnologija [21]. The reason of this preference is to establish an objective assessment for face shape prediction via the FP2FSPS. To obtain the feature sets of faces, a feature-based face feature extraction algorithm was borrowed from Cox et al. [22] and it was fundamentally modified and adapted to this application. In comparison to the approach proposed in [22], increasing the number of the reference points from 35 to 53 points helped to represent the faces more accurately and sensitively. In addition, face feature sets were shaped from x-y coordinates of the face reference points, not distances or average measures as in [22].

The ANN module that was used to analyze the existence of any relationship among Fs&Fs was implemented with the help of 3-layered MLP structure that was trained with SCG algorithm. The SCG algorithm adjusts the weights and biases of the ANN according to its learning strategy. The details of SCG algorithm was given in [23].

The ANN module is the most critical and important module of the system. Because, all other modules are on duty, either in pre-processing or post-processing of this main process. The training process is started with applying the feature sets of Fs&Fs to the system as inputs and outputs, respectively. The system achieves the training process with these feature sets according to the learning algorithm and the ANN parameters. Even if the feature sets of Fs&Fs are required in training, only fingerprint feature sets are used in test. The outputs of the system for these unknown test data indicate the success and reliability of the system and it must be clearly shown by evaluating the ANN outputs against to the proper metrics.

The traditional metrics of an ordinary biometric system are no longer appropriate to characterize the performance of the FP2FSPS. So, in addition to the ROC curve, the results of the system are evaluated by considering the following numerical metrics: mean squared error (MSE), sum squared error (SSE), mean absolute error (MAE), absolute percentage error (APE) and Mean APE. APE is the measure of accuracy of the system as a percentage for a test face. MAPE shows mean APE that is average of the absolute percentage errors per each coordinate of the feature sets of the faces. Similarly, MAE is an average of the absolute errors per each coordinate of the feature sets of the faces. These metrics were explained in [24]. To evaluate the system results comprehensively a visual evaluation platform was also created by drawing the ANN outputs and their desired outputs in the same page as overlapped. In order to achieve the visual evaluation effectively, a face re-construction module was developed to convert the ANN outputs and desired outputs to visual face shapes.

Consequently, for a more objective comparison, the performance and accuracy of the system have been evaluated and presented on the basis of the combination of these metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.

5. EXPERIMENTAL RESULTS

The proposed FP2FSPS discussed in previous section was implemented to conduct the experiments efficiently. The dedicated and developed software supplies all of the system parts to be controlled properly. The experimental data sets used in the test contain only feature sets of fingerprints of the test people. The face feature sets of these people were never used in training processes of ANN. They were used for evaluation of the system performance. The inputs and the outputs of the system were vectors sized 298 and 106, respectively. Producing the faces as close to the real one as possible is critical for this study. The metrics MSE, SSE, mean APE, mean MAE and mean MAPE were 0.00044, 1.90770, 4.29903, 0.01572 and 0.04056, respectively. The ROC curve of the test results is given in Figure 3.

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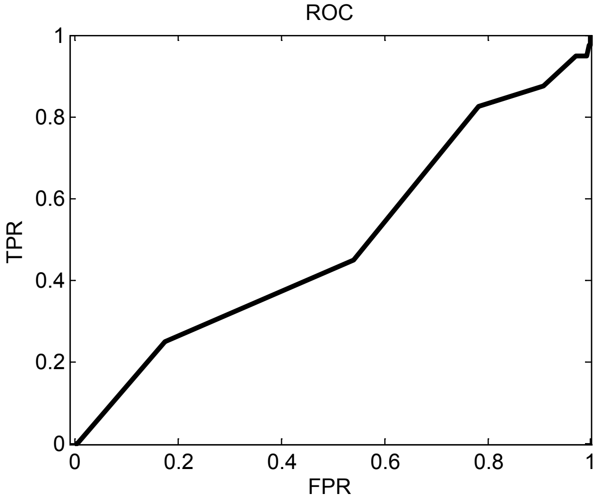

Figure 3. ROC curve of the test results (TPR: True Positive Rate, FPR: False Positive Rate)

According to the test results the proposed system performs the tasks with high similarity measures to the desired values. For the purpose of more realistic and visual evaluation, all of achieved test results and desired values of them have been drawn on the same platform as shown in Figure 4. Dark continuous and light dashed lines in the figure represent the desired and the generated face features, respectively. In addition, to show the overall system performance graphically, APE, MAE and MAPE values belonging to all test results were demonstrated in Figure 5. Based on the results and observations, the presented FP2FSPS can be used as an intelligent model to predict face shapes from fingerprints, effectively.

6. CONCLUSION AND FUTURE WORKS

The principal objective of this paper is to generate automatically the face shapes including eyes, mouth and face border from only fingerprints with high accuracy. This article successfully presents an approach to predict face shapes from only fingerprints. The relationships among biometrics and achieving an unknown biometric feature from a known biometric feature are also experimentally shown in the proposed study. When each of the results was visually elaborated, it is very clear to see that there are very close matches among ANN outputs and their desired values. The results presented in this work reports that there are more than twelve close matches considering mouths and face borders and also more than fifteen close matches at eyes. The experimental results provided very encouraging and successful results in achieving the face shapes from fingerprints automatically. These results confirmed once more that there are close relationships among Fs&Fs. It is expected that this study will lead to create new concepts, research areas, and especially new applications in the field of biometrics and forensics.

In future studies, investigations will be conducted to enhance the face generation processes. It is also studied on modeling the relationships among Fs&Fs to prove not only experimentally but also mathematically. In addition, the performance and accuracy of the system should be shown by using a larger multi-modal database including biometric features of people from different countries.

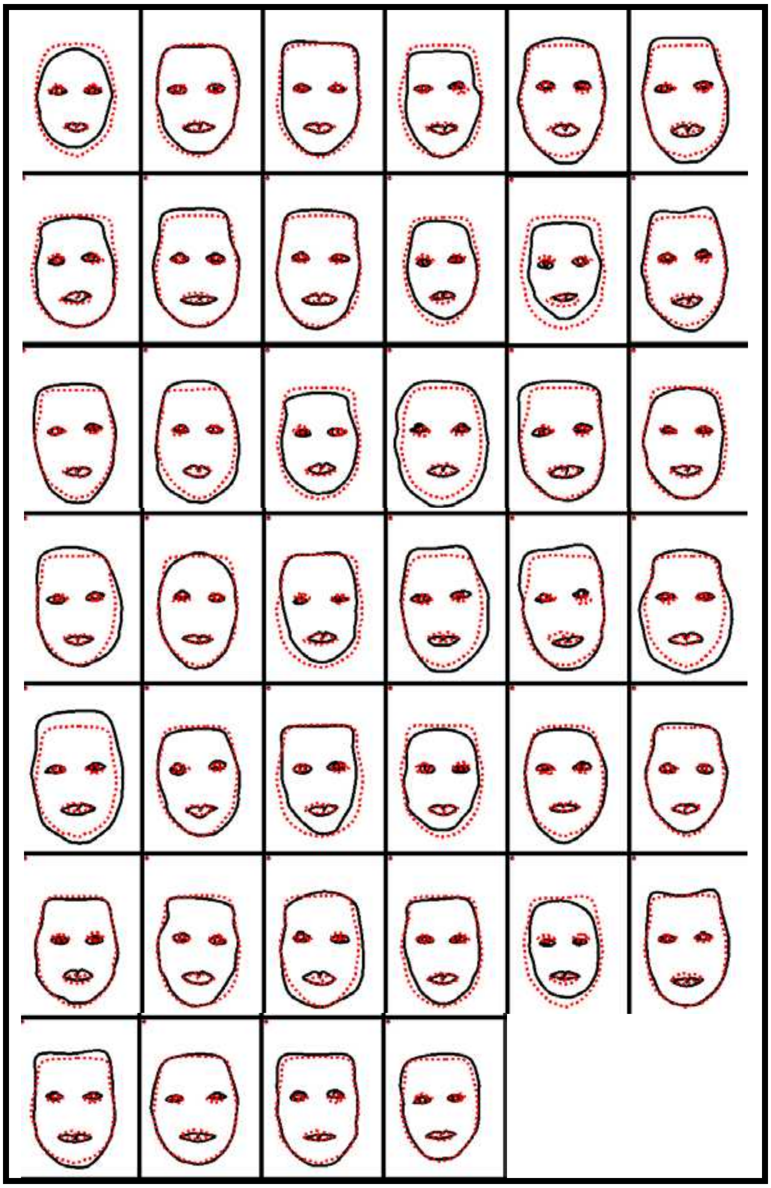

Figure 4. Representing the test faces achieved from the FP2FSPS and their desired values.

7. ACKNOWLEDGEMENTS

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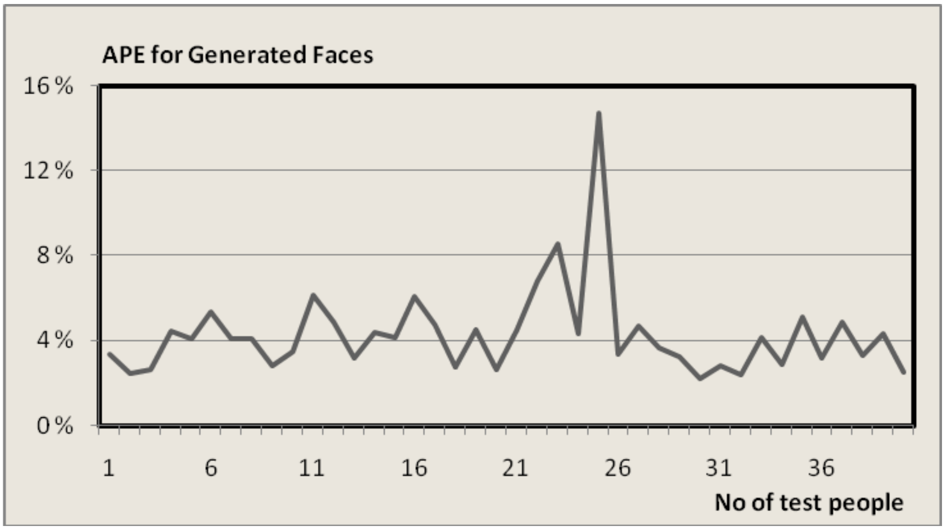
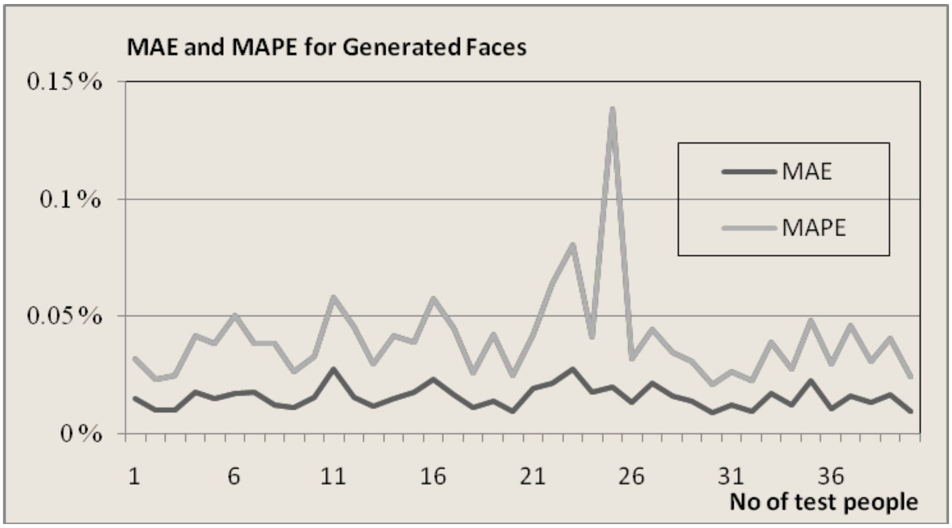


(a) APE Values



(b) MAE and MAPE Values

Figure 5. Error values for generated faces.

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1**An intelligent face features generation system from fingerprints**

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Abstract

75**In this study, a** novel intelligent system **based on artificial neural networks**

was designed and introduced for generating faces from fingerprints with high accuracy. The proposed system has a number of modules including two feature enrolment modules for acquiring the fingerprints and faces into the system, two feature extractors for extracting the feature sets of fingerprint and face biometrics, an artificial neural network module that was configured with the help of Taguchi experimental design method for establishing relationships among the biometric features, a face re-constructor for building up face features from the results of the system, and a test module for test the results of the system.

67**10-fold cross validation** technique **was used** for evaluating **the** performance **of**

the system. The results have shown that the

face features can be successfully generated from only fingerprints.

82It can be concluded that the proposed study significantly

and directly contributes to biometrics and its new applications. Key Words: Information security, biometrics, artificial neural networks. 1. Intro duction Accurately identifying a person is the most critical process in biometrics-based security applications, and are used for recognizing and determining an individual identity based on his or her

1physical or behavioral characteristics, including fingerprint, face, ear, hand geometry, voice, retina, iris, etc.

[1, 2].

29Any human physiological or behavioral characteristic might be used as a biometric characteristic as long as it satisfies these following requirements: universality, uniqueness, permanence and

collectability [2]. Biometric based identification systems have been widely utilized in many security applications. Biometrics is a marvelous technology that is lower in cost, faster and more accurate. It also covers the great performance expectations compared with the existing alternatives like PINs or passwords [1]. Over the last couple of decades, biometric based recognition systems have been widely investigated, a number of biometric features have been studied, tested, and successfully deployed in

1applications including information security, law enforcement, surveillance, forensics, smart cards, access control,

time/place control points and computer networks, etc. [2], [3]. Achieving

1a biometric feature from another biometric feature is a challenging

idea. This transformation might be useful for many applications especially security applications. When the literature was reviewed, no study was found investigating relationships among the biometric features or obtaining one feature from the others, except the present authors [4–12]. Sağıroğlu and Özkaya have experimentally showed there exists a relationship among the biometric features of faces and fingerprints. The authors proposed novel approaches for generating the face borders [4], the

1face contours including face border and ears [5], the face models including eyebrows, eyes and mouth [6], the inner face parts including eyes, nose and mouth [7], the face parts including eyes, nose, mouth and ears [8], the face models including eyes, nose, mouth, ears and face border [9], the face parts including eyebrows, eyes, nose, mouth and ears [10], only eyes [11] and the face parts including eyebrows, eyes and nose

[12]

1**from only fingerprints without any need** for **face information or images.**

It is clear from the studies that

1**an unknown biometric feature can be achieved from a known biometric feature. The**

scope of our study here is to develop an automatic and intelligent biometric system capable of obtaining inner face features including eyes, nose and mouth from just

1**fingerprints, without having any priori knowledge about faces,**

with the help of optimally designed

1**artificial neural network (ANN) models. In order to**

achieve that, an intelligent face model generation system from fingerprints (fingerprint to face features: F2FF) was developed and introduced in this study. The ANN models used for establishing the relationships among fingerprints and faces were optimally designed with Taguchi experimental design

69**technique. This paper is organized as follows. Section II briefly describes**

1**background information on biometrics, automatic fingerprint identification and verification systems (AFIVSs), face recognition systems (FRSs)**

and multi modal biometric systems (MMBSs), respectively. Sections III and IV briefly introduce ANNs and Taguchi experimental design technique, respectively. Section V highlights the novelty of the proposed technique, presents basic notation, definitions, performance metrics related to the F2FFs and explains the steps of the proposed approach followed. Section VI demonstrates the experimental results achieved in this study.

1**Finally, the proposed** approach **is concluded and discussed in Section**

VII. 2. Overview of biometrics Biometrics is used to recognize an individual or to determine

76**an individual** identity **based on his/her** physical **or behavioral** biometric **characteristics**

[2]. In general, a biometric system operates its tasks in the following three steps:

47**acquiring biometric data from a person, extracting a feature set from the acquired data, and** recording the **feature set**

into a database or

73**/and comparing** the **feature set against the template** feature **set in the**

1**database. When a user wants to authenticate him/** herself **to the system, a fresh biometric feature** is taken from **the** user, the **same feature extraction algorithm is applied, and the extracted feature set is compared to the template. If**

80**they are sufficiently similar according to the** criterion, the **user is**

finally authenticated [13]. Biometric based systems lead to user convenience, reduce fraud and secure systems and society [14]. Figure 1 illustrates a general biometric system having four modes depending on the application status [14]: the enrolment, the verification, the identification and the screening. The two most popular biometric systems are AFIVSs and FRSs. Fingerprint is a sort of identity card that 184 ????????? ???? ?????????? ??????? ??? ?? ? ????????? ???? ???????? ????????? ???????? ?????? ?? ?????? ???????? ???????????? ???? ?? ?????????? ? ??????????????? ?????????? ???????? ????????? Figure 1. A generic biometric system. people carry with them continuously [15]. The

1**AFIVSs might be broadly classified as being minutiae-based, correlation-based and image-based systems** [16]. **A good survey about these systems** is **given in**

[2]. In our study, feature sets of the fingerprints a minutiae-based approach was preferred. The

1**minutiae-based** approach **rely on the** comparison **for similarities and differences of local ridge attributes and their relationships to make a personal identification**

[17, 18]. In general the comparison is based on representing two important attributes including end points and bifurcations. The end point

9**is defined as the point where a ridge ends** suddenly. **A bifurcation is defined as the point where a ridge** separates **or diverges into branch ridges**

[3, 17]. If these local attributes and their

1**parameters are computed relative to the** global attributes called **singular points** including core and delta

1**points which are highly stable, rotation, translation and scale invariant,** these local attributes **will then** also **become** rotation, translation **and scale invariant** [19], [20–22]. **Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate**

[21, 23].

1**Main steps of the operations in the minutiae-based AFIVSs are summarized as** follows: **selecting the image area, detecting the singular points, enhancing, improving and thinning the fingerprint image, extracting the minutiae points and calculating their parameters, eliminating the false minutiae** points, **representing the fingerprint images** properly **with their feature sets, recording the feature sets into a database, matching the feature sets, testing** the system results **and evaluating the** performance of the **system. The**

1**performance of the minutiae-based techniques relies on the accuracy of all these** processes. Especially **the feature extraction and the use of sophisticated matching techniques to compare two minutiae sets often** affect **the performance.**

Face recognition is a biometric method that identifies the individuals using the features of their faces. It is an active research area

43**with applications ranging from static, controlled mug-shot verification to dynamic, uncontrolled face identification in a cluttered background**

[17].

1**In general, a FRS consists of three main steps.**

These steps cover

34**detection of** the **faces in a** complicated **background, localization of** the **faces followed by extraction of** the **features from the face regions and finally** identification or **verification**

tasks [24].

1**Face recognition process is really complex and difficult due to numerous factors** effecting **the appearance of an individual's facial features such as 3D**

pose, facial expression, hair style, make up,

lighting, background, scale, noise and face occlusion [24, 25]. The

41**most popular approaches to face recognition are based on either the location and shape of** the **facial attributes** [26] or **the** overall analysis **of**

the face images [14, 24]. Also

1**many effective and robust methods for face recognition have been proposed**

in the literature [3, 17], [24–29]. Multi-model biometric systems (MMBSs) are gaining acceptance among designers due to their perfor- mance superiority over the unimodal systems that have some limitations about accuracy, processing time and vulnerability to spoofing [28]. The advantages of multimodal biometrics have been reported with repetition in the literature. It is indicated that combining multiple sensors, biometric features, units, matchers or enrolment templates of a user could improve the accuracy of a biometric system [30]. Also MMBSs were designed as a fusion of the various biometric data at different

57**levels such as the feature extraction level, the score level or the decision level**

[31]. Detailed information about MMBSs can be found in [13]. 3. Artificial neural network

7**Artificial neural networks have been applied to solve many problems**

in the literature [27, 32–37].

7**Learning, generalization, less data requirement, fast computation, ease of implementation and software and hardware availability features have made** the **ANNs very attractive for** many **applications** [33, 34]. **These fascinating features have also made them popular in** biometrics **as well**

[27, 32,

1**35–37]. Multilayered perceptron (MLP) is one of the most popular ANN architectures**

used in biometrics. MLP structures consist of

1**three layers: input, output and hidden layers. One or more hidden layers might be used. The**

1**weights are adapted with the help of a learning algorithm according to the** error **occurring in the calculation. The** error **can be** calculated **by subtracting the ANN** output **from the desired** output. ANNs **might be trained with many different learning algorithms**

[33]. To get better and faster performance,

1**Taguchi experimental design technique was used to** achieve optimum **parameters of ANN** structure, **in this**

study. 4. Taguchi experimental design technique The Taguchi experimental design technique

4**is a well-known** and **robust design**

technique [38–41] involving an efficient planning of experiments in engineering applications [40]. This technique

4**enables the optimum combination of design parameters to be determined from a minimum number of experiments,**

4**ensures the reproducibility of the experimental results and**

recommends devising a smallest possible fractional factorial design. With the help of this technique [40]: 1.

39**The performance characteristics to be optimized** are selected. 2. **The**

39**experiments based on orthogonal array to obtain information on the** system performance and **its variability** are designed **and**

executed. 3. Mean

27**and variance techniques to obtain optimal setting of parameters for robust** system **design**

are analyzed and used. The results from the experimental

53**runs can provide information in the form of the deviation from the mean of** a **set**

[41].

84**Verification of the robust design** results **is** then **performed**

[40]. Analyses of means are used

70**to determine the best** ANN parameters **to achieve optimal performance. Analysis of variance**

is also used to determine the

27**factors that have significant effects on the signal-to-noise** ratio **(SNR)**

[41]. 5. Proposed system As briefly expressed in the previous sections, fingerprint verification and face recognition topics have been received significantly more attention. The aims of this study are to establish a relationship among fingerprints 186 and faces (Fs&Fs), to analyze this relationship and to generate the face features from fingerprints, requiring no priori knowledge about faces, using a system equipped with the best parameter settings. The majority of these aims were achieved in this work. Our motivation in this study arises from biological and physiological conditions, as briefly reviewed below.

1**It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment [42]. Physical appearances of faces and fingerprints are also a part of an individual's phenotype. In the case of fingerprints, the genes determine the general characteristics of the pattern [42]. In dermatoglyphics studies, the maximum generic difference between fingerprints has been found among individuals of different races. Unrelated persons of the same race have very little generic similarity in their fingerprints, parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in** the **identical twins, which** have **the closest genetic relationship [43]. Some scientists in biometrics** field **have focused on analyzing the similarities in fingerprint minutiae patterns in identical twin fingers [42],** and have **confirmed the** claim that the **fingerprints** of identical twins **have a large class correlation. In addition to this class correlation,** other correlations **based on generic attributes of the** fingerprints **such as ridge count, ridge width, ridge separation and ridge depth** were **also found to be significant in identical twins [42]. In the case of faces, the situation is very similar with the fingerprints. The**

general characteristics of the face patterns were determined by the genes and

60**the maximum generic difference between** faces **has been found among individuals of different races.**

Very little generic similarity was found in the faces of unrelated persons of the same race.

40Parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the

1maximum generic similarity is observed in the identical twins, which bear the closest genetic relationship. A number of studies have especially focused on analyzing the significant correlation among faces and fingerprints of the identical twins [42, 44–46]. The large correlation among biometrics of identical twins was repeatedly indicated in the literature by declaring that identical twins would cause vulnerability problems in biometrics based security applications [47]. For example, the similarity measure of identical twin fingerprints is reported as

much as 95% [47].

1In the case of faces of identical twins, the situation is very similar. The reason of

1this high degree similarity measure was explained in some studies as: identical twins have identical DNA except for the generally undetectable micro mutations that begin as soon as the cell starts dividing. Fingerprints and faces of identical twins start their development from the same DNA, so they show considerable generic similarity [48]. The similarity among biometric features of identical twins is given in Figure 2. Fingerprints of identical twins and a fingerprint of a stranger are given in Figure 3 [46].

Generally, it is a simple process for an individual to distinguish the fingerprints or faces of different people. However, distinguishing the fingerprints or faces of identical twins is a very difficult and complicated process, not only for the eyes and brain of a human being but also for biometric based recognition systems. The

1high degree of similarity in fingerprints and faces of identical twins,

of examples are shown in Figure 4, converts this simple recognition process to a hard task. ??? ??? ??? ??? Figure 2. Different biometrics of

1identical twins [45]. (a) Retina, (b) Iris, (c) Fingerprint (d) Palm print. ??? ??? ??? Figure 3. Fingerprints of identical twins (a, b) and fingerprint of someone not related (c) [46].

188 ??????????????? ???????????????? ???????????????? ???????????? Figure 4. Fingerprints and faces of identical twins. In the light of the explanations above,

1identical twins possess strong similarity in both fingerprints and faces.

Increasing and decreasing distinctions **of** such **similarities are also the same among** non-related **people. Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces.**

In order to investigate this assumption, an intelligent system was developed in this study. Developed ANN based intelligent system generates the inner face features including eyes, nose and mouth of an individual from only one fingerprint of the same individual. The system consists of two data enrolment

65**modules, two feature extraction modules, an** ANN **module, a** test and evaluation **module and a** face re-construction **module.**

In the system, the data enrolment modules help to store biometric data

1**of individuals into the biometric system database. During this process,**

Fs&Fs of individuals have been captured. Two types of data are used in this study. A real multi-modal database including Fs&Fs belonging to 120 people was established with the help of Biometrica model FX2000 for fingerprints and a Canon digital camera for faces. Only a frontal face image and index finger of the right hand were taken into consideration in this study. The feature extraction modules were used to extract discriminative feature sets from the acquired data. In the fingerprint feature extraction module, extracting

1**local and global feature sets of the fingerprints, including singularities, minutiae points and their parameters**

was achieved. Fingerprint feature sets were computed using a software development kit (SDK) developed by Neurotechnologija, ans was selected to establish objective assessment for the F2FF prediction. This SDK is known as an effective, robust and reliable AFIVS in the field of biometrics and uses a minutiae-based algorithm. Detailed explanation of algorithms,

1**information of fingerprint feature sets and their storage format** are **given in**

[49]. Face feature sets were obtained from the faces in face feature extraction module. 38 reference points were used for representing a face model in this work. To obtain the face feature sets,

1**a feature-based face feature extraction algorithm was borrowed from Cox et al.** [29] **and** it was **fundamentally modified and adapted to this**

system. In comparison to the approach proposed in [29],

1**increasing the number of reference points** helped **to represent the faces more accurately and sensitively.**

In addition, in this study

1face feature sets were shaped from x-y coordinates of the face model reference points, not distances or average measures as in

[29].

1It was also observed that feature sets having enough information about faces

increase the system's performance on achieving faces accurately. The reason why a feature-based method was preferred for obtaining the feature sets of the faces might be explained as follows: a minutiae-based approach was used to get the feature sets of the fingerprints. Actually, minutiae

13-based approaches rely on the physical features of the fingerprints.

Therefore it is reasonable that the feature sets of both Fs&Fs should be obtained in the same way. Because of these reasons, a feature-based approach was used to obtain the feature sets of the faces as well. The ANN module is used to analyze the existence of any relationship among Fs&Fs. This part of the system was implemented with the help of MLP structure.

1MLPs were trained with the input vectors and the corresponding output vectors with different parameter levels based on Mean Square Errors (MSEs) and Absolute Percentage Errors (APEs). In order to determine the best parameter settings of MLP structure, L-16 (8 ∗∗ 1 2 ∗∗ 3) Taguchi experiment is designed. Taguchi design factors and factor levels are given in Table 1. Training algorithms, the number of layers, the number of inputs and the transfer functions were main Taguchi design factors

to be considered. Levels of

1Taguchi design factors were 8, 2, 2 and 2,

respectively. MLP training algorithms that have been

1considered and used in this work were Powell-Beale conjugate gradient back propagation (CGB), Fletcher-Powell conjugate gradient (CGF), Polak-Ribiere conjugate gradient (CGP), Gradient descent (GD), Gradient descent with adaptive learning coefficients (GDA), One step secant (OSS), GDA with momentum and adaptive learning coefficients (GDAM) and Scaled conjugate gradient (SCG). In this 190 study, the number of layers was 3 and 4; and the number of inputs was 200 and 300.

The transfer functions that have been considered and used were Tangent Hyperbolic (TH) and Sigmoid Function (SF). Table 1.

1**Taguchi design factors and factor levels.** Taguchi Design **1 2 3 4**

Levels 5

1**6 7 8 Training Algorithms CGB CGF CGP GD GDA OSS GDAM SCG** Design **Number of Layers 3 4** Factors **Number of Inputs 200 300 Transfer Functions** TH **SF**

Via Taguchi design, the best MLP parameters

1**were determined according to** the **MSEs. Main** effects **plots were taken into** consideration **while analyzing the effects of parameters on response factor.** The main effects **plots**

for this study are given in Figure 5 and Figure 6. They show the effects of each factor to the response factor, both in numerical and graphical representation. Plots of the main effects

1**might help to understand and to compare changes in the level means, and to indicate the influence of effective factors more precisely.**

28**When the line is parallel to the x-axis,**

it means that

28**each level of the factor affects the response in the same way and** there **is**

no main effect. When the line has a slope, then

8**a main effect** exists **and different levels of the factor** effect **the response differently. Greater slopes** display **the**

8**magnitude of the main** effects. **By comparing** the **slopes of the lines, relative magnitude of the** factor **can be determined.**

Smaller values are better in Figure 5, and larger values are better in Figure 6. ?? ??????????????????? ???????????????? ????????????? ??? ??? ??? ??? ??? ??? ??? ??? ?? ??????? ??? ??? ???????????????? ? ? ?????????????????? ??? ??? ??? ??? ??? ??? ??? ?? ?? Figure 5. Result table for mean of Means. ?? ?? ????????????? ?? ?? ?? ?? ?? ?? ?? ??????????????????? ???????????????? ??? ??? ??? ?? ??? ???? ??? ??? ? ? ???????????????? ?????????????????? ??? ??? ?? ?? Figure 6. Result table for mean of SNR. As can be seen from Figure 5, 1**training algorithms** have **the largest main effect on MSE.**

Also, all other factors have considerably effected to the system performance according to the main effects plot for means. However, only this plot is

8**not enough to derive a conclusion,** for **it is necessary to** consider **the**

59**main effects plot for SNR** that **is** given **in Figure**

6. In this work, the

59**main effects plot for SNR** has confirmed that **the**

training algorithm has the largest main effect on the response factor. The number of

1**layers in MLP structure and transfer** function is **also considerably effective.** MSE was **not mainly** effected **by the** number **of inputs. Finally it can be clearly said that considering the main** effects **plots, MSEs will get smaller if the parameter settings given in Table** 2 **were followed.**

Table 2. Results for ANN factors. Factors Means Parameter Settings SNR Optimum Design Training Algorithm CGF CGF CGF Number of

1**Layers 3 3 3** Number **of Inputs** 200 **300 300 Transfer Functions SF SF SF The**

CGF algorithm was determined the best training algorithm in the ANN parameter analysis in Taguchi design technique. The CGF algorithm updates weights and biases

77**according to the conjugate gradient with Fletcher-Reeves updates.**

3**This algorithm calculates the mutually conjugate directions of search with respect to the Hessian matrix of f directly from the function evaluation and the gradient evaluation, but without the direct evaluation of the Hessian of the function f** [50]. This **algorithm**

is defined as follows [50]: 192 1 : repeat 2 :

3**Compute ∇f(x0) and h0 = ∇f(x0)** 3 : **for i = 1, ..., n − 1 do** 4 : replace **xi = xi−**

1 + λi−1hi−1, where λi

52−1 **minimizes f(xi−1** + λi−1hi **−1)** 5 : **Compute ∇f(xi)** 6 : **if i < n then** 7: hi = **−∇f(xi)**

+ ‖‖∇∇ff(x(xi−i)1‖)2‖ 2 hi−1 8 : end if 9: x0 = xn 10 :

3**end for** 11: **until halting** criterian **The quantity**‖‖∇∇ff(x **(xi−i)1‖)‖**

22 hi−1

30**is added to the gradient at** every **iteration when** f **is a quadratic form (positive definite);** it **results in a set of mutually conjugate vectors.**

The details of CGF algorithm can be found in references [51] and [52]. The ANN module was the most critical and important module of the system, because all modules of the system except the ANN module are on duty, either in pre-processing or post-processing of the main process. The

1**ANN structure and its training parameters were determined to achieve accurate solutions. The training** process was **started with applying the fingerprint and face feature sets** to **the system as inputs and outputs, respectively. The sizes of** the **input and** the **output vectors were also 300 and** 76, **respectively. The** size of input **(the**

feature sets of fingerprints) is fixed to 300 because of their different lengths. If the size of input is larger than 300 it is fixed to 300. If the size of inputs is smaller than 300, zeros are added to the string to complete it to 300. The

1**system achieves the training processes with these feature sets according to the learning algorithm and the ANN parameters which were obtained** via the **Taguchi design method. Even if the feature sets of Fs&Fs were required in training, only fingerprint feature sets were used in test. It should be emphasized that these fingerprints used in test were** to the system **totally unknown biometric data. The** outputs of **the** system for **the unknown test data indicate the** success and reliability **of the system. The success and reliability of the system**

in achieving faces from fingerprints

1**must be clearly shown by evaluating the ANN outputs against** to **the proper metrics. In**

this study, to characterize the performance of the F2FF system, appropriate performance metrics were used. The results of the system were tested and the performance

1of the system was evaluated in 10-fold cross validation technique using

traditional, numerical, graphical and visual evaluation platforms by considering the following metrics: 1. Traditional Metrics: These metrics are:

44false match rate (FMR), false non match rate (FNMR) and the receiver operating characteristics (ROC) curve. The percentage of the

9impostor pairs, whose matching score is greater than

a threshold value, is called FMR; and the

1percentage of genuine pairs, whose matching score is less than

the threshold value, is known as FNMR.

9FMR(t) & FNMR(t) representation is derived from the score distributions

at all thresholds t. In the literature, it is more common to use a ROC curve to represent the performance and accuracy of the biometric systems. 2. Numerical Metrics: These metrics are:

66mean squared error (MSE), sum squared error (SSE), mean absolute error (MAE),

absolute percentage error (APE) and Mean APE.

1MSE and SSE are two of the most used metrics to quantify the amount by which an estimator differs from the true value of the quantity being estimated.

MSE measures the

1average of the square of the “error.” SSE is the sum of squared predicted values in a standard regression model [53]. In general, less the MSE and SSE, better the model performs in its estimation.

As the name suggests,

46MAE is a quantity used to measure how close forecasts or predictions are to the eventual outcomes

[53]. In this study, MAE is an

1**average of the absolute errors per each** coordinates **of the feature sets of the faces.**

1**APE is the measure of accuracy in a fitted time series value. It usually expresses accuracy as a percentage**

[53, 54]. SSE, MSE, MAE, APE and MAPE (Mean APE) are defined in equations (1)–(5), respectively. In the equations,

1**Oi is the output of the ANN, Di is the desired value of the Oi and ei = Di − Oi . n** MSE = **1**

n

85**(Di − Oi)2 ∑i=1 n** SSE = **(Di**

− Oi)2

72**∑i=1 n n** M AE = **1** |Di − Oi| = **1 n** |ei| **∑i=1** n **∑i=**

1 AP E = |Di − Oi| n ∑i=1 Di M AP E = 1 n |Di − Oi| n i=1 Di ∑ (1) (2) (3) (4) (5) 3. Visual Metrics: To evaluate the system results comprehensively a visual evaluation platform is created by drawing the ANN outputs and the desired outputs in the same form. In order to achieve the visual evaluation easily, effectively and efficiently, a face re-construction module was developed. Face re-construction module is flexible software to convert the

1**ANN outputs and desired outputs to visual face models.**

1**Indeed, it basically** transforms **the reference points of the face models to the lines. The** developed **software is capable of** drawing **the results of actual and calculated values of the same face in** different platforms, in **the same platform or**

on the real face image of involved individual as well. Consequently,

1**for a more objective comparison, the performance and accuracy of the system have been evaluated**

and

1**presented on the basis of the combination of these metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.** 194 6. **Experimental results**

In order to achieve the experiments, a compact software solution was developed. Dedicated software helps all of the system parts to be controlled properly and conducts the experiments easily and efficiently. The experimental image sets used in the test contain only fingerprint images of the test people. It should be emphasized that those image sets were unknown data sets for the system. As mentioned earlier, the inputs and the outputs of the system were vectors sized 300 and 76, respectively. Producing a face as close to the real one as possible is critical for this study. 10-fold cross validation technique was applied in this study for evaluating the performance. The developed systems were trained and tested 10 times with 10 different data sets. Max's, mean's, min's and Standard deviations (STD DEV) of MSE, SSE, Min's, Max's, Averages and Standard deviations of MAEs, APEs and MAPEs were calculated for each fold and Min's, Max's, Averages and STD DEV's of them were given in Table 3. Table 3. Results for numerical analysis. MAX MEAN MIN STD DEV MEAN's of APEs 5.44755 4.66573 3.95484 0.57996 MAX's of APEs 14.42700 8.84229 5.98220 3.35286 MIN's APEs 3.64400 2.56562 1.88900 0.51441 STD DEV's of APEs 3.40146 1.85673 1.09255 0.86028 MSEs 0.00086 0.00050 0.00064 0.00013 SSEs 0.78660 0.45800 0.58511 0.11938 MEAN's MAEs 0.02290 0.01993 0.01796 0.00197 MAX's MAEs 0.04745 0.03311 0.02553 0.00725 MIN's MAEs 0.01641 0.01134 0.00861 0.00234 STD DEV's of MAEs 0.01020 0.00682 0.00474 0.00185 MEAN's of MAPEs 0.07168 0.06139 0.05204 0.00763 MAX's of MAPEs 0.18983 0.11635 0.07871 0.04412 MIN's MAPEs 0.04795 0.03376 0.02486 0.00677 STD DEV's of MAPEs 0.04476 0.02443 0.01438 0.01132

83**In order to** illustrate **the accuracy of the proposed**

approach, obtained

78**results were compared with the results of a** previous **study**

presented in [7] which shared the same goal. The comparison results are given in Table 4. Due to 10-fold cross validation technique not used in the previous study, in this comparison, means of 10-fold cross validation results of the proposed approach in this study and the results of the previous study were benchmarked.

81**As shown in Table** 4, clearly **the proposed** approach has **better** performance **than**

the previous study, with significant superiority in MSE and SSE. Table 4 shows that

1**Taguchi experimental design technique** increases **the** accuracy **and** performance **of the system.**

In addition, 10-fold cross validation technique obtained the opportunity to measure the robustness and accuracy of the system in a more reliable platform in comparison to previous studies. The results indicate that the

1**proposed system performs the tasks with** measures of **high similarity to the desired values**

and its performance is also better than the previous study [7]. The ROC curves of the

1**results for each fold of 10-fold cross validation** technique are given **in Figure**

7. To represent the results in a more realistic format, test results and desired values of them have been drawn together in the same platform and given in Figure 8

1**for each fold of 10-fold cross validation**

technique. All evaluation results including traditional, numerical and visual metrics were obtained from the raw ANN results that were scaled in between [0 1], without any post processing like rescaling. Table 4. Results for MSE and SSE. Previous Study [7] Proposed Approach MSE 0.00110 0.00050 SSE 3.24160 0.45800 ? ??? ??? ??? ??? ??? ??? ? ? ??? ??? ??? ??? ? ??? Figure 7. ROC curves of the results for 10-fold cross validation. ??? ??? Figure 8. Test results for both desired and achieved face parts for each 10-fold cross validation. 196 ?? ??? ?? ?? ?? Figure 8. Contunied. ??? ?? ?? Figure 8. Contunied. The

1**APE, MAE and MAPE values belonging to all test results for each fold of 10-fold cross validation** are shown **in Figure** 9. **Averages of all APEs, MAEs and MAPEs** are **given in Figure**

10. ?????? ???? ?? ????????? ????? ??? ???? ???? ?????? ?? ?????? ??? ?????? ? ?????? ? ?????? ??? ?? ?????? ? ? ? ? ? ? ? ? ? ?? ?? ???? ?????? ?? ?? ?? ?????? ?????? ??????? Figure 9. APE, MAE and MAPE values of generated faces. 198 ?????? ???? ???? ?? ????????? ????? ??? ???? ???? ??? ?????? ?????? ??? ???? ?????? ?????? ?????? ???? ?????? ? ? ? ? ? ? ? ? ? ?? ?? ?? ?????? ?? ?? ???? ?????? ?????? ??????? ???? ???? ???? ???? Figure 9. Contunied. ? ???? ??? ?????? ? ??? ? ? ? ? ? ? ? ? ? ? ?? ???? ??????? ?? ??????? ????? ?????????? ???? ???? ???? ??? ??? ?????? ???? ??? ??? ???? ???? ? ? ? ? ? ? ? ? ? ?? ???? ??????? ?? ??????? ????? ?????????? Figure 10. Average

1**results for APEs** (a), **MAEs and MAPEs** (b) **for each fold.**

The results indicate

1**that the proposed system is very successful in** recovering **faces from only fingerprints.**

7. Conclusion and future work ????? ?? ??????????????? ???????? ???? ?????? ?????? ?????? ??? ?????? ?????? ?????? ?????? ?????? ? ? ? ? ? ? ? ? ? ?? ?? ?? ?? ?? ???? ?????? ?????? ???????

1**This study presents a** novel **approach based on** ANN **for generating faces from**

fingerprints

without requiring any priori knowledge about faces. The experimental results have shown that Taguchi experimental design technique very much helps design better ANN structures, which achieve better performance, to represent the close relationships among fingerprints and faces. 10-fold cross validation technique has proved the high accuracy of the system in three different evaluation platforms. Owing to 10-fold cross validation technique, the results of the system were evaluated properly, and reliability and robustness of the system were well demonstrated. For example, each fold has more than ten close matches in the nose and mouth areas. The difficulties faced during the implementation of the system were: establishing a multi-modal database covering fingerprints and faces, the lack of evaluation metrics to determine the results clearly, developing the software throughout the study, applying new concept to the practice, and dealing with many parameters. It is concluded that the fundamental novelty and diversity of the proposed approach, over most other studies in biometrics, is representation of the relationships among biometric features, such as fingerprints and faces, and to demonstrate the approach which can successfully predict face features from only fingerprints using the ANN that was re-configured with the best parameter settings predicted via the Taguchi experimental design technique. The results have shown that the prediction accuracy improved

1**with the help of Taguchi experimental design** method. **The** results **of**

this study confirmed once more that there are strong relationships among Fs&Fs. It is expected that this study will

1**lead to create new concepts, research areas, and especially new applications in the field of biometrics** and forensics. **The** authors are studying **the**

modeling of these relationships to demonstrate, not only experimentally, but also mathematically the efficacy of this approach for further studies.

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16**Generating One Biometric Feature from Another: Faces from Fingerprints**

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48**Turkey; E-Mail:** ss@gazi **.edu.tr * Author to whom correspondence should be addressed; E-Mail:** neclaozkaya@erciyes **.edu.tr.**

16**Received: 20 January 2010; in revised form: 4 March 2010 / Accepted: 22 March 2010 / Published: 28 April 2010 Abstract:**

1**This study presents a** new **approach based on** artificial neural networks **for generating** one biometric feature **(faces) from** another (only **fingerprints).**

An automatic and intelligent system was designed and developed to analyze the relationships among fingerprints and faces and also to model and to improve the existence of the relationships. The new proposed system is the first study that generates all

73**parts of the face including eyebrows, eyes, nose, mouth,**

ears and face border from only fingerprints. It is also unique and different from similar studies recently presented in the literature with some superior features. The parameter settings of the system were achieved

1**with the help of Taguchi experimental design** technique. **The**

1**performance and accuracy of the system have been evaluated**

with 10-fold cross validation technique using qualitative evaluation metrics in addition to the expanded quantitative evaluation metrics. Consequently, the results were

1**presented on the basis of the combination of these** objective and subjective **metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.**

Experimental results have shown that one biometric feature can be determined from another. These results have once more

85**indicated that there is a strong relationship between**

fingerprints and faces.

30**Keywords: biometrics; fingerprint; face; artificial neural network; intelligent system;**

Taguchi 1. Introduction Biometrics has become more and more important solutions to overcome vulnerabilities of the security systems for people, companies, corporations, institutions and governments. Person identification systems based on biometrics were used in primarily

17**limited applications requiring high security tasks like criminal identification and police work** in the beginning, **more recently they have been**

used in a wide range of

1**applications including information security, law enforcement, surveillance, forensics, smart cards, access control,**

etc. because of their reliability, performance and accuracy of identification and verification processes [1-4]. When the biometric literature was reviewed, it was found that there was extensive literature on fingerprint identification and face recognition. The researchers were mostly focused on designing more secure, hybrid, robust and fast systems with high accuracy by developing more effective and efficient techniques, architectures, approaches, sensors and algorithms or their hybrid combinations [1,2]. Generating

1**a biometric feature from another is a challenging**

research topic. Generating face characteristics from only fingerprints is an especially interesting and attractive idea for applications. It is thought that this might be used in many security applications. This challenging topic of generating face parts from only fingerprints has been recently introduced for the first time by the authors in series of papers [5-13]. The relationships among biometric features of the faces and fingerprints (Fs&Fs) were experimentally shown in various studies covering the generation of: ? face borders [5], ?

1**face contours, including face border and ears** [6], ? **face models, including eyebrows, eyes and mouth** [7], ? **inner face** masks **including eyes, nose and mouth** [8], ? **face parts, including eyes, nose, mouth and ears** [9], ? **face models including eyes, nose, mouth, ears and face border** [10], ? **face parts, including eyebrows, eyes, nose, mouth and ears** [11], ? **only eyes** [12], ? **face parts, including eyebrows, eyes and nose**

[13], ? face features,

1**including eyes, nose and mouth** [14] and ? **face** shapes, **including eyes, mouth and face**

border [15]. In these studies, face parts are predicted

1**from only fingerprints without any need** of **face information or images.**

The studies have experimentally demonstrated that there are close relationships among faces and fingerprints. Although various feature sets of faces and fingerprints, different parameter settings and reference points were used to achieve the tasks with high accuracy from only fingerprints, obtaining the face parts including the inner face parts with eyebrows and face borders with ears has not been studied up to now.

82**In order to** achieve **the** generation **task** automatically **with high accuracy,** a complete system was developed. This system combines all the other recent studies introduced in the literature and provides more complex and specific solutions for generating whole face features from fingerprints.

21**In order to** improve **the performance of the proposed**

study,

1**Taguchi experimental design technique was** also **used to** determine best **parameters of** artificial neural network **(ANN)** models used **in this**

generation. In order to evaluate and demonstrate the results more precisely, 10-fold cross validation technique with both quantitative (objective) evaluation metrics and expanded qualitative (subjective) evaluation metrics were used. So the performance and accuracy were demonstrated in a more reliable way with a limited database in comparison to the previous studies. The

70**paper is organized as follows. Section 2 reviews the**

1**background information on biometrics, automatic fingerprint identification and verification systems (AFIVSs),** and **face recognition systems (FRSs).**

Section 3 briefly introduces ANNs. Section 4 presents the motivations of this study as well as investigates the previous works about relationships among fingerprints and faces. Section 5 describes the evaluation methods. Section 6 presents the novelty of the proposed system including basic notations, definitions and various steps of the present method, the intelligent biometric feature prediction system (IBFPS). The experiments including numerical and graphical results of IBFPS are depicted in Section 7.

1**Finally, the proposed** work **is concluded and discussed in Section**

8. 2. Background of Biometric Systems Biometric features covering

1**physical or behavioral characteristics including fingerprint, face, ear, hand geometry, voice, retina, iris** recognition, **etc.**

are peculiar to the individual, reliable as far as not being transferable easily and invariant during the life time [1]. Typical biometric systems include enrollment, identification, verification, recognition, screening or classification processes. The steps in system tasks are as follows: biometric data acquisition, feature extraction, registration, matching, making decision and evaluation. Biometric data were obtained from people with the help of a camera- like-device for the faces and fingerprint scanner for the fingerprints, etc. In general, after data acquisition processes, the digital representation of the biometric data of the people were obtained in the digital platform. Feature extraction processes were applied to this digital form of the biometric features and feature sets were registered to the biometric system

1**database. When a user wants to authenticate him/** her self **to the system, a fresh biometric feature** was acquired, **the same feature extraction algorithm is applied, and the extracted feature set is compared to the template** in the database. **If**

these feature sets of the input and the template biometric features

1**are sufficiently similar according to the** matching criteria, **the user"**

s final decision was taken and the user was authenticated at the end of the matching process [3,14]. Data acquisition, verification, identification and screening phases are the main types of biometric based systems [4]. The types are summarized as: Type I: The biometric data acquisition phase is the first step of the other three phases. Enrollment, classification and recording of the biometric features are achieved in this phase. Type II: The verification phase is the most commonly used biometric system mode in the social life like person identification systems in physical access control, computer network logon or electronic data security [2,4]. In that phase an individual"s identity is usually achieved via a user name, an

6**identification number, a** magnetic card, **a smart card, etc.** At **the**

end of the verification phase, the submitted claim of the identity is either rejected or accepted [1]. Type III: The identification phase is commonly used in

17**applications requiring high security tasks like criminal identification and police work.**

In that phase, the system tries to recognize an individual"s identity with using just his or her biometric feature. The system fails if the person is an undefined person in the system database. In that case, the output of the system is a combination list of identities and the scores indicates the similarity among two biometric features [15]. According to some pre- defined rules about similarity measures, the system decision was produced in this phase. Type IV: The screening phase is like the identification phase. The results of determination

32**whether a person belongs to a watch list of identities**

or not is displayed in this phase.

32**Security at** airports, **public events and other surveillance applications** are some of **the screening**

examples [4,16].

81**A typical** biometric **system is** given **in Figure** 1. **The** processes in **the**

system are achieved according to the arrows illustrated

6**in the** figure **depending on the application** status. Figure 1. **A** typical **biometric system.**

Identification & Screening Acquiring Biometric Data Pre-processing steps Features Extraction Matching (Searching N records) User"s Identity OR User can not be identified Biometric Data Acquisition Verification Biometric Data + User ID ID Pre-processing steps Claimed Identity Biometric Data + User Pre-processing steps Features Extraction Features Extraction N templates 1 Template Matching (Searching 1 record addressed) System Database True OR False These sort of biometric recognition systems make people, systems or information safer by reducing the fraud and leading to user convenience [4]. Two of most popular biometric features used in the biometric based authentication systems are fingerprints and faces. Fingerprints based biometric systems are called AFIVSs and faces based biometric systems are called FRSs. Fingerprints are unique

77**patterns on the** surface **of the fingers. Fingerprints** represent **the**

people with high accuracy because of having natural identity throughout the life of which are not forgotten anywhere or not be lost easily. They were reliably and widely used to identify the people for a century due to its uniqueness, immutability and reliability [17]. In AFIVSs, ridge-valley structure of the fingerprint pattern, core and delta points called singular points, end points and bifurcations called minutiaes are used for identifying an individual. These structures are given in Figure 2. Many approaches to AFIVSs have been presented in the literature [1,2,15,17-30]. The

1**AFIVSs might be broadly classified as being minutiae-based, correlation-based and image-based systems** [18]. **A good survey about these systems** was **given in**

the reference [1]. The

1minutiae-based approaches rely on the comparisons for similarities and differences of the local ridge attributes and their relationships to make a personal identification

[19-21]. They

11attempt to align two sets of minutiae from two fingerprints and count the total number of matched

minutiae [4]. If a minutiae and its parameters are computed relative to the singular

1points which are highly stable, rotation, translation and scale invariant, the minutiae will then become rotational, translational and scale invariant [15,22-24]. Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate

[23,25,26]. The

56general methods to detect the singular points are Poincare-based [27], intersection-based [23] or filter- based

[28] methods. Figure 2. Ridge-valley structure and features of a fingerprint. Ridge Endpoint Valley Cores Bifurcation Deltas

1Main steps of the operations in the minutiae-based AFIVSs are summarized as: selecting the image area; detecting the singular points; enhancing, improving and thinning the fingerprint image; extracting the minutiae points and calculating their parameters; eliminating the false minutiae sets; properly representing the fingerprint images with their feature sets; recording the feature sets into a database; matching the feature sets; and, testing and evaluating the system [29]. The steps and

their results are given in Figure 3, respectively. Although the

1performance of the minutiae-based techniques relies on the accuracy of all these steps, the feature extraction and the use of sophisticated matching techniques to compare two minutiae sets are often more effective on the performance.

11Global patterns of the ridges and valleys are compared to determine if the two fingerprints are aligned in the correlation -based AFIVSs. The

12template and query fingerprint images are spatially correlated to estimate the degree of similarity between them. The performance of correlation-based techniques is affected by non-linear distortions and noises in the image.

50In general, it has been observed that minutiae-based techniques perform better than correlation-based ones

[30]. The decision is made using the

96features that are directly extracted from the raw image in the

37image-based approaches that might be the only viable choice when image quality is too low to allow reliable minutiae extraction

[18]. Figure 3. Main operational steps of minutiae-based AFIVSs [29]. Step 1: Input fingerprint image Step 2: The image area and the singular points Step 3: Enhanced and Improved image Step 4: Thinned image Step 5: The matching area and the fingerprint feature sets Step 6: Matching scores and the decision (Enroll, identify, verify or screen) 10 0 ROC Step 7: Test and evaluation FNMR(t) 10-1 ROC 10-2 -2 -1 10 10 10 0 FMR(t) Faces are probably the most highly accepted and user-friendly characteristics in the field of biometrics. Face recognition is an attractive and

1active research area with several applications ranging from static

to dynamic [19]. In

1general, a FRS consists of three main steps covering detection of the faces in a complicated background, extraction of the

features from the face regions and localization of the faces and finally recognition tasks [31]. The steps used in face processing in fingerprint to face task are illustrated in Figure 4.

1Face recognition process is really complex and difficult due to numerous factors affecting the appearance of an individual"s facial features such as 3D pose, facial expression, hair style, make-up,

etc.

67In addition to these varying factors, lighting, background, scale, noise and

face occlusion, and many other possible factors make these tasks even more challenging [31]. The

6most popular approaches to face recognition are based on each location and shape of the facial attributes including eyes, eyebrows, nose, lips and chin and their spatial relationships or the overall analysis of the face image representing a face as a weighted combination of a number of canonical faces

[4,32].

1Many effective and robust methods for the face recognition have been also proposed

[2,19,31-35]. The methods are categorized in four groups as follows [34]:

15human knowledge of what constitutes a typical face was encoded in the

knowledge-based methods.

58Structural features that exist even when the pose, viewpoint or lighting conditions vary

to locate faces were aimed to find in the feature invariant

15methods. Several standard patterns of a face were used to describe the face as a whole or the facial features separately in template matching based methods. Finally,

31**appearance-based methods operate directly on images or appearances of** the **face objects and process the images as two-dimensional holistic patterns.**

Figure 4. Main processes of face processing for fingerprint to face task system. Step 1: Capture the image and detect the faces in a complicated background. Step 2: Extract the features from the face regions to generate the template. Step 3: Compare the inputs with templates and declare matches. As explained earlier, processing fingerprints and faces are really difficult, complex and time consuming tasks. Many approaches, techniques and algorithms have been used for face recognition, fingerprint recognition and their sub steps. It is very clear from the explanations that dealing with generating faces from fingerprints are really more difficult tasks. Because of the tasks to be achieved in this article, faces, fingerprints, pre and post processing of them, applying many methods, implementing them in training and test procedures, analyzing them with different metrics, and representing the outputs in visual platform, etc. have made the prediction task more difficult. 3. Artificial Neural Networks ANNs are biologically inspired intelligent techniques

20**to solve many problems** [36-40]. **Learning, generalization, less data requirement, fast computation, ease of implementation and software and hardware availability features have made ANNs very attractive for** many **applications**

[36

80**].There has been a growing** research **interest in** security and recognition **applications**

based on intelligent techniques and especially ANNs which are also very popular in biometric-based applications [5-13,29,34,35,37-40].

1**Multilayered perceptron (MLP) is one of the most popular ANN architectures**

and can be trained with various learning algorithms. Because an

94**MLP structure can be trained by** many **learning algorithms,**

it

21**has been successfully applied to a variety of problems** in **the**

literature [36]. The MLP structure consists of

1**three layers: input, output and hidden layers. One or more hidden layers might be used. The**

74**neurons in the input layer** can be treated **as buffers** and distribute **input**

signal to the

9**neurons in the hidden layer.** The output of **each neuron in the hidden layer**

is obtained from the sum of the multiplication of all input signals and weights that follow all these input signals. The sum can be calculated as a function. This function

9**can be a simple threshold function, a** hyperbolic tangent **or a** sigmoid **function.**

The outputs of the neurons in

other layers are calculated in the same way. The function

9can be a simple threshold function, a hyperbolic tangent or a sigmoid function. The outputs of the neurons in

other layers are calculated in the same way. The

1weights are adapted with the help of a learning algorithm according to the errors occurring in the calculation. The errors can be computed by subtracting the ANN outputs from the desired outputs. MLPs might be trained with many different learning algorithms

[36]. A general form of the MLP is given in Figure 5. Figure 5. General Form of the MLP.

87Input Layer Hidden Layer Output Layer INPUTS OUTPUTS

ssSS neurons weights y=f(v) In this study, the MLP based model structure having single hidden layer was used to model the relationships and to generate the faces. The MLP models were trained with the conjugate gradient algorithm updating

4weight and bias values according to the conjugate gradient with Powell-Beale restarts

(CGB) [41]. 4. Motivation of the Proposed Approach It is especially difficult to believe that there is a relationship between biometric features because of their characteristics such as their uniqueness. This research was difficult and challenging. As an initial step, biological and physiological evidences regarding the relationships among biometric features to support this study were investigated. The evidences and observations given below help us to believe that it is worth investigating the relationship among fingerprints and faces. These are given below: 1.

1It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment [42]. Physical appearances of faces and fingerprints are also a part of an individual‟s phenotype. In the case of fingerprints, the genes determine the general characteristics of the pattern [42]. In dermatoglyphics studies, the maximum generic difference between fingerprints has been found among individuals of different races. Unrelated persons of the same race have very little generic similarity in their fingerprints, parent and child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum generic similarity is observed in identical twins, which is the closest genetic relationship [43]. 2. Some of the scientists in biometrics have focused on analyzing the similarities in fingerprint minutiae patterns in identical twin fingers [42]. They absolutely confirmed that the identical twin fingerprints have a large class correlation. In addition to this class correlation, correlation based on other generic attributes of the fingerprint such as ridge count, ridge width, ridge separation, and ridge depth was also found to be significant in identical twins [42]. 3. In the case of faces, the situation is very similar with the circumstances of fingerprints. The

1maximum generic similarity is observed in the identical twins, which is the closest genetic relationship [43]. 4. A number of studies have especially focused on analyzing the significant correlation among faces and fingerprints of identical twins [42,44-46]. The large correlation among biometrics of identical twins was repeatedly indicated in the literature by declaring that identical twins would cause vulnerability problems in security applications [47]. The similarity measure of identical twin fingerprints is reported as

95% [47]. The reasons

1of this high degree similarity measure were explained in some studies as follow: ? Identical twins have exactly identical DNA except for the generally undetectable micro mutations that begin as soon as the cell starts dividing [46]. ? Fingerprints of identical twins start their development from the same DNA, so they show considerable generic similarity [48]. The similarity among biometric features of identical twins was given in Figure 6. Fingerprints of identical twins and fingerprint of another person were given in Figure 7 [46].

The

1high degree of similarity in fingerprints or faces of identical twins

is demonstrated in Figure 8. 5. Previous Work on Relationships among Fingerprints and Faces In the light of explanations in the previous section,

1identical twins have strong similarities in both fingerprints and faces. Increasing and decreasing directions of these similarities are also the same among the people. Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces.

The results reported by the authors have been also experimentally shown that relationships among fingerprints and faces exist [5-13]. Figure 6. Different biometric features of

1identical twins [45]. (a) Retina, (b) Iris, (c) Fingerprint and (d) Palm print. Figure 7. Fingerprints of identical twins (a, b), and fingerprint of another person (c) [46].

(a) (b) (c) Figure 8. Fingerprints and faces for identical twins. (a) Twin–I [44] (b) Twin–II [44] (c) Twin–III (d) Twin–IV [46] In the studies [5-13], relationships among fingerprint and face parts were investigated and various face parts were tried to be predicted from just fingerprints step by step from simple to complex. At the beginning of the processes, authors have tried to generate only face borders [5], only eyes [13] and face contours [6] from just fingerprints. In further steps of the process, the ANN structures were improved, trained and tested to predict static face parts [7,8,12]. After these studies, ANN structures used in predicting process were advanced owing to the experiences of the authors and more complex face parts would be generated with high accuracy [9-11]. Finally, this study introduces for the first time the most complex representation of the relationships among fingerprints and faces. The studies [5-13] presented the experimental results in different platforms such as traditional evaluation platform, numerical evaluation platform and finally a visual evaluation platform. However it should be noted that because of having limited data sets covering 120 people in those studies, 10

92-fold cross-validation should be applied to illustrate the performance of

the system. Randomly selected train-test data sets are no longer appropriate to characterize the performance of the system. It can lead into error in evaluating the performance of the system by causing imperfect comments on the results. In 10-fold cross validation process, the database was randomly divided into 10 different data group sets covering 90% of all data set in training and the rest 10% in test data sets for each fold. The proposed system was trained and tested with these ten different training-test data sets. After ten different trainings, 10 test processes were then followed. Accuracy and performance of the ANN models for each fold were computed according to the appropriate evaluation metrics covering expanded quantitative and qualitative metrics. The ANN structures of previous studies were designed and reconfigured with randomly selected or experimentally obtained parameters. It is well known that finding appropriate parameters depending on applications is very difficult. It takes time and suitable parameters are established with the help of trails and errors. To do it systematically, as mentioned before, this study also presents obtaining best ANN parameters like numbers of the layers, numbers of the inputs, training algorithms and activation functions

1**with the help of Taguchi experimental design** technique. In **the**

previous studies [5-13], performance and accuracy of the proposed model are evaluated by quantitative metrics and/or human assessment presented in a graphical form. In this paper, both the quantitative

2**measures (i.e., objective) carried out automatically by computers**

expanding the metrics available in the literature and the qualitative (subjective) evaluation perceived by observation were taken into account. Next section describes these quantitative and qualitative evaluation metrics. 6. Evaluation metrics To generate more accurate face features from fingerprints without having any information about faces is successfully achieved and introduced in this study. It needs to be emphasized that evaluating results was an important, critical and difficult part in this study. There were not certain criteria to elaborate the results precisely. For doing that, the

1**success and reliability of the** proposed **system** having proper metrics **in achieving** face parts **from** only **fingerprints must be clearly** illustrated. **The**

traditional metrics of an ordinary biometric system like FMR-FNMR representation and ROC curve are no longer appropriate to characterize the

88**performance of the system** because **of the proposed system**

is not an ordinary biometric-based recognition system. In this study, more test procedure and performance metrics covering combination of the quantitative and qualitative measures are introduced for better evaluations. The

75**details of these** metrics **are** explained **in the following subsections.**

6.1. Quantitative Evaluation Metrics These metrics are briefly introduced in the following subsections. 6.1.1. FMR-FNMR Curve and The ROC Curve FMR-FNMR and ROC curves are commonly used as evaluation metrics for biometric based recognition systems. The curves and determination procedure were detailed in [1]. The null (Ho) and alternate (H1) hypotheses for the biometric verification problem and associated decisions according to these hypotheses were given in Table 1 and Table 2, respectively. If “T” is

78**stored as a** biometric **template of** a **person** and “I” **is the**

acquired input of a biometric feature, the hypotheses for biometric verification are written for Ho:I≠T input and template do

3**not come from the same person** and **H1: I=T input** and template come **from the same person.** Table 1. **The** null and **the**

alternate hypotheses for the biometric verification. Formulas Definition Ho: I≠T Input and template are not

3**from the same person H1: I=T Input** and template are **from the same person**

Table 2. Decision types. Formulas Definition Do: I≠T A person is not the same person to be claimed D1: I=T A person is the same person to be claimed In general, two types of errors are encountered in a typical biometric verification system:

3**mistaking biometric measurements from two different fingers** being **the same finger (false match) and mistaking two biometric measurements** for **the same finger** being **two different fingers (false non-match). These errors are**

given in Table 3 for Type I and Type II, respectively. The

3**verification involves matching T and I using a similarity measure s(T,I). If the matching score** s(T,I) **is less than the system threshold t, then decide** Do, **else decide D1.** To evaluate **the**

system, it must be collected the

3**scores generated from a number of fingerprint pairs from the same finger (the distribution p(s|H1 = true) of such scores is traditionally called genuine distribution), and scores generated from a number of fingerprint pairs from different fingers (the distribution p(s|** Ho = **true) of such scores is traditionally called impostor distribution).**

69**FMR is the probability of Type I error and**

could be defined as the

3**percentage of impostor pairs whose matching score greater than or equal to t, and FNMR is the** probability **of**

Type II error and could be defined as

61**the percentage of genuine pairs whose matching score is less than t.**

Table 3.

97**Two types of errors in a** typical biometric **system.**

Error Type Formulas Definition Type I: (FMR) 1

95**FMR ? P(D1 | H0 ? true) ? ? P(** s | H0 ? **true)**

ds t

3**False match** rate: **(D1 is decided when** Ho **is true), Type II:**

(FNMR)

3**t FNMR ? P(** D0 | **H1 ? true) ? ? P(s** | H1 ? **true)ds**

0

3**False non-match** rate: (Do **is decided when H1 is true).** Among **FMR** and FNMR, there **is**

a strict tradeoff.

3**If t is decreased to make the system more tolerant with respect to input variations and noise, then FMR increases; vice versa, if t is raised to make the system more secure, then FNMR increases accordingly.** So the **system**

performance was reported

3**at all operating points (threshold, t)** in ROC curves **by plotting** FNMR as **a** function of FMR [1]. 6.1.2.

91**Mean Squared Error (MSE)** and **Sum Squared Error (SSE)**

1**MSE and SSE are the metrics to quantify the amount by which an estimator differs from the true value of the quantity being estimated.**

These metrics were used for evaluation of the performance and accuracy of the systems that were investigating the relationships among fingerprints and faces in the literature [5]-[13]. MSE is to measure the

1**average of the square of the error. SSE is the sum of squared predicted values in a standard regression model. In general,** the **less the SSE,** the **better the model performs in its estimation.**

MSE and SSE were given in Equations (1) and (2),

1**respectively. In the Equations,** n **is the** number **of the** test people, Oi **is the** output **of the** system **and Di**

is the desired value of Oi: MSE ? 1n ?in?1 ? Di ? Oi ? 2 (1) n 2 SSE ? ? ? Di ? Oi ? i ?1 (2) 6.1.3. Absolute Percentage Error (APE) and Mean APE (MAPE)

1**APE is the measure of accuracy in a fitted time series value. It usually expresses accuracy as a percentage**

[50]. APE is also commonly used as an evaluation metric in the similar studies aimed to investigate among fingerprints and faces in the literature [5]-[13]. These metrics were given in Equations (3) and (4). In the equations, n is the number of the test people,

1**Oi is the output of the** system and **Di is the desired value of Oi:**

APE ? ?i?1 DiD?iOi n MAPE ? 1n?i?n1 DiD?iOi (3) (4) 6.1.4. Mean Absolute Error (MAE)

1**MAE is a quantity used to measure** generations or predictions **how** they are **close**

to the eventual outcomes. This metric was used in this study at first. It should be noted that, this metric was linked appropriately with the application proposed in this paper. As the name suggests,

1**MAE is an average of the absolute errors.**

It is calculated

1**average of the absolute errors per each** coordinate **of the feature sets of the faces** in **the**

proposed study. The formulation of MAE is given in Equation (5).

1**In the** equation, **Oi is the output of the ANN, Di is the desired value of the Oi and ei = Di − Oi:** 1 n **1 n** MAE ? **n** ?i?1 **Di ? Oi** ? n **?i?1**

ei (5) 6.2. Qualitative Evaluation Metrics In previous studies [5-13], quantitative evaluation platforms were prepared to help the researchers determine whether the obtained results are similar to their desired values or not. In this study, in addition to that, a qualitative analysis was carried out in order to determine whether the obtained results are similar to their desired values, how much the results are close to their desired values and how accurately the system performs the task. Although the quantitative metrics indicate the system performance clearly in the numerical manner, they

2**do not provide any information about the perceived visual quality of the** results. **Accordingly, a psychophysical experiment was designed and carried out below. The aim of this qualitative analysis was to determine which** quality **of** results **the**

system produces

2**imagery with the highest perceived** results **quality by human observers.**

Qualitative assessment method applied to this study was explained below. In

2**order to obtain an objective qualitative assessment of the**

results,

2**a standard psychophysical rank- ordering paradigm** [51,52] **was employed** to modify the **paradigm**

for our study.

2**Essentially, this paradigm consisted of presenting the participants with the** results **and asking each participant to rank order** of **each of those** results **based on their**“qualities” **by assigning each of the** results in **a numerical value. Specifically,**

in this study the test results for each fold were presented to the participants by asking each participant to the degree of the results in a numerical value from 1 to 5. The meanings of the numerical values are given below: 1: the results are very different from the desired values, the system failed. 2: the results are a bit similar to the desired values, but the system cannot be accepted as successful. 3: the results are similar to the desired values, the system success is average. 4: the results are very similar to the desired values, the system is above average. 5: the results are nearly the same or the same with the desired values, the system is very successful. Before starting the experiments

2**each participant was asked to read standardized instructions explained the task**

clearly.

2**All participants were allowed** to **ask questions regarding the task before beginning the** experiments. **At the beginning of the**

experiments, for each trial, twelve results for each 10-fold cross validation were simultaneously displayed. At the end of each checking process, he or she gives a mark for the test results of each fold. At the end of this part of the evaluation, each participant checks all test results of the 10-fold cross validation containing 120 test people and gives a mark for each fold to evaluate the results if face prediction is successfully achieved or not. 7. The Proposed System: Intelligent Biometric Feature Prediction System (IBFPS) In order to achieve the task of prediction, a proposed system called IBFPS was developed and implemented. The new approach successfully generates total face features containing all of the

1**face parts including** eyebrows, **eyes, nose, mouth and face** contours **including** face border and **ears**

from only fingerprints without having any information about faces in this study. In addition, the relationships among Fs&Fs are also analyzed and discussed in more details with the help of different evaluations criteria. Assume that this relationship among faces and fingerprints

68can be mathematically represented as: y = H(x) (6) where y is a vector

indicating the feature set of the face model and its parameters achieved from a person, x is a vector representing the feature set of the fingerprint acquired from the same person, H(.) is a highly nonlinear system approximating y onto x. In this study, H(.) is approximated to a model to generate the relationship among Fs&Fs with the help of ANN models. The proposed system is based on MLP-ANN model having the best parameters with the help of Taguchi experimental design technique [53-55].

1MLPs were trained with the binary input vectors and the corresponding output vectors with different parameter levels based on Mean Square Errors (MSEs) and Absolute Percentage Errors (APEs). In order to determine the best parameters of MLP- ANN structure, L-16 (8** 1 2**3) Taguchi experiment is designed. Taguchi design factors and factor levels were given in Table 4. Training algorithms, the numbers of layers, the numbers of inputs and the transfer functions were main Taguchi design factors

and 8, 2, 2 and 2 to be considered as factor levels, respectively. MLP-ANN training algorithms

1considered and used in this work were Powell-Beale conjugate gradient back propagation (CGB), Fletcher-Powell conjugate gradient (CGF), Polak-Ribiere conjugate gradient (CGP), Gradient Descent (GD), Gradient Descent with adaptive learning coefficients (GDA), One Step Secant (OSS), GDA with momentum and adaptive learning coefficients (GDAM) and scaled conjugate gradient (SCG) [56]. In this

study, the numbers of layers were set to 3 and 4, the numbers of inputs were 200 and 300. Hyperbolic Tangent (HT) and Sigmoid Function (SF) activation functions were considered and used in MLP-ANN structures. In Taguchi design, best parameters of MLP-ANNs

1were determined according to MSEs. Main effect plots were taken into considerations while analyzing the effects of parameters on the response factor. These plots

1might help to understand and to compare the changes in the level means and to indicate the influence of effective factors more precisely.

According to these plots,

1training algorithms had the largest main effect on MSE.

The numbers of

1layers in MLP- ANN structure, and transfer functions were also considerably effective. MSEs were not mainly affected by the numbers of inputs. Finally it can be clearly said that considering the main effect plots, MSEs will get smaller if the parameter settings given in Table 5 were followed. Table

4.

1Taguchi design factors and factor levels. LEVELS Taguchi Design

1 2 3 4 5 6 7 8

1Training Algorithms CGB CGF CGP GD GDA OSS GDAM SCG DESIGN FACTORS Number of Layers 3 4 Number of Inputs 200 300 Transfer Functions HT SF

Table 5.

1Results for ANN Parameter Analysis. Factors Parameter Settings Means SR Optimum Design Training

Algorithms CGB CGB CGB Numbers of

1Layers 3 3 3 Numbers of Inputs 300 300 300 Transfer Functions SF SF SF After the

1ANN structure and its training parameters were determined to achieve accurate solutions, the training processes were started with applying the fingerprint and face feature sets of the people to the system as inputs and outputs, respectively. The sizes of input and output vectors were also 300 and 176, respectively. The

1system achieves the training processes with these feature sets according to the learning algorithm and the ANN parameters which were obtained from Taguchi design method. Even if the feature sets of Fs&Fs were required in training, only fingerprint feature sets were used in test. It should be emphasized that these fingerprints used in test were totally unknown biometric data to the system. The outputs of the system for the unknown test data indicate the accuracy of the system. The success and reliability of the system

1must be clearly shown by evaluating the ANN outputs against the proper metrics in

achieving face parts from fingerprints. The block diagram of the MLP-ANN used in this work is given in Figure 9. According to the best parameters obtained from Taguchi method, the MLP-ANN models were trained with a conjugate gradient algorithm

4that updates weight and bias values according to the

26conjugate gradient back propagation with Powell-Beale restarts (CGB). The CGB is a network training algorithm that updates weight and bias values according to the CGB algorithm [56]. Conjugate gradient

algorithms (CGAs) execute very effective search in the conjugate gradient direction. Generally,

4a learning rate is used to determine the length of the step size. For all CGAs, the

4search direction will be periodically reset to the negative of the gradient. The standard reset point occurs when the number of iterations is equal to the number of network parameters (weights and biases), but there are other reset methods that can improve the efficiency of training [57]. One such reset

method was proposed by Powell [41], **based on an earlier version proposed by Beale**

[58].

90**Figure 9. The block diagram of the** MLP NN structure. **Feature**

Sets of Fs&Fs Input vectors representing the fingerprints MLP-ANN Output vectors representing the faces Test Inputs MLP-ANN Test Outputs Desired Outputs Evaluation Process Results 1. evaluation with qualitative metrics 2. evaluation with quantitative metrics In principle, feed forward

7**neural networks for non-linear system identification**

can use all CGAs. In the first iteration, the CGAs

5**start out by searching in the steepest descent direction** that was given **in**

Equation (7): p0 ? ?g0 (7) In the equation,

7**po and go are the search vector and gradient, respectively.**

Consider xk

7**is the estimate of the minimum at the start of the k-th iteration. The k-th iteration then consists of the computation of search vector pk from which new estimate** xk+1 **is obtained.**

It is given in Equation (8): xk?1 ? xk ??k pk (8) In the equation, αk is

7**previous knowledge based upon the theory of the method**

or obtained by linear search. The

10**next search direction is determined so that it is conjugate to previous search directions.** Combining **the new steepest descent direction**

10**with the previous search direction is the general** way **for determining the new search direction.**

It is given in Equation (9). In the equation, βk is a positive scalar and the

57**various versions of gradient are distinguished by the manner constant βk is computed**

[59]: pk ? ?gk ? ?k pk?1 (9)

14**Periodically resetting the search direction to the negative of the gradient** improves the CGAs. **Since** Powell-Beale **procedure is ineffective, a restarting method that does not abandon the second derivative information is needed.**

According to Powell-Beale technique it

4**will restart if there is very little orthogonality left between the current gradient and the previous gradient. This is tested with the inequality** given in Equation

42**(10). If this condition is satisfied, the search direction is reset to the negative of the gradient:**

gTk?1gk ? 0.2 gk 2 (10) The inputs and outputs of the system were digital representations of fingerprints and faces of the people, respectively. The feature vectors of the fingerprints obtained from a commercially available software development kit contain the

1**local and global feature sets of the fingerprints including singularities, minutiae points and their parameters**

[60]. Detailed explanation of the feature extracting algorithms, extensive

1**information of fingerprint feature sets and their storage format** were **given in**

the reference [60]. These discriminative data represent the people with high accuracy. The outputs were the feature vectors of the faces obtained from

1**a feature-based face feature extraction algorithm** that **was borrowed from Cox et al.** [61] **and fundamentally modified and adapted to this**

application.

1**Increasing the number of** the **reference points** 35 **to** 88 helped to **represent the faces more accurately and sensitively.**

1**Face feature sets were** also **shaped from** Cartesian **coordinates of the face model reference points not distances or average measures as** given **in**

the reference [61].

1**It was also observed that feature sets** contain **enough information about faces**

for getting them again with high accuracy. The face reference points on the template, on the face image of a person from our database and re- construction of the face model from the reference points were given in Figure 10. Figure 10. Face reference points a) on the template, b) on a real face image from the database, c) re-construction of the face model from the reference points. (a) (b) (c) A flexible design environment for the face model re-construction converting

1**the ANN outputs and/** or the **desired outputs to visual face models**

was also included in the software developed.

1**Indeed, it basically** transformed **the reference points of the face models to the lines. The software is capable of** plotting **the results of actual and/** or **calculated values of the same face in the same platform or**

in different platforms. It also illustrates the ANN results on the real face images. So, the face model re-construction handles an important task for the system by creating two different visual evaluation platforms. This re-construction process enables users to achieve the qualitative evaluation processes easily, efficiently and automatically with the support of the developed useful graphical interface. At the beginning of the experiment, an enrollment procedure was followed for collecting the biometric data from the people. This enrollment procedure helps to store fingerprint and face biometrics of

1**individuals into the biometric system database. During this process**

a real multimodal database belonging to 120 persons was established. Ten fingerprints of each individual were scanned with a fingerprint scanner, and a 10 face image having different angles were also taken from the people using a digital camera. A set of examples including fingerprints and faces of an individual were given in Figure 11 and Figure 12, respectively. Only one frontal face image and one fingerprint belonging to the

30**right hand index finger for each person were used in this study.**

Figure 11. Ten fingerprint images of an individual from our database (from “1” to “10”, from the left to the right, respectively). Figure 12. Face images captured from different angles from an individual. The software developed achieves all the tasks of the system from the enrollment step to evaluation step completely. It is expected that

1**generating faces from fingerprints without** having **any priori knowledge about faces**

will find considerable attention in science and technology of biometrics, security and industrial applications. As mentioned earlier, evaluating this system is very critical from the point of being a pioneering study claiming to generate the facial parts including the inner face parts with eyebrows and face contour with ears from only fingerprints. So, the success and reliability of the system must be clearly depicted. In that case, test processes in this article were mainly divided into two main parts: qualitative and quantitative evaluation platforms. 8. Experimental Results

1**In order to achieve the** experiments **effectively,** automatically **and** easily, **a**

software platform covering Figures 3, 4 and 5 was developed. In order to generate faces from only fingerprints, the following experiments were performed as: 1. Read fingerprints and faces from database 2. Obtain the feature sets of fingerprints and faces. 3. Establish a network configuration for training 4. Find optimum parameters with the help of Taguchi method. 5. Train the network with selected parameters. 6. Save the results for further uses. 7. Test the system against to the proper evaluation metrics. 8. Test the system performance based on 10-fold cross validation technique. 9. Investigate

2**whether the quantitative (objective) evaluation results are consistent with qualitative (subjective) evaluations based on human perceptual assessment.** Previous **experiments**

on predicting faces from fingerprints [5-13] have shown that the relationship between fingerprints and faces can be also achieved with high accuracy. In the current experiments, an automatic and intelligent system based on artificial neural network is designed to generate the faces of people from their fingerprints only. The proposed study has some advantages on the previous studies in the literature. These features are given below as: 1. All

1**face parts including eyebrows, eyes, nose, mouth,** face border **and ears**

were successfully predicted in this study for the first time. 2. The optimal parameters of ANN model parameters were determined with the help of Taguchi experimental design technique. 3. Qualitative evaluation procedure was followed in addition to the quantitative evaluation procedure with some extra quantitative metrics. 4.

83**10-fold cross validation** technique **was** applied **to** analyze **and** to evaluate **the**

performance and the accuracy of the system more precisely. Producing the face models as close as possible to the real one is the most critical part of the system in this study. In

66**order to** evaluate **the performance of the** developed **system** effectively, test **experiments were** mainly focused **on** two qualitative and quantitative evaluation platforms: a 10-fold cross- validation method was followed, as mentioned earlier. The results of the system were tested against to these evaluation metrics. FMR&FNMR and ROC curve representations were also given in Figure 13. In the figure, ROC curves were plotted for each fold separately, but the FMR&FNMR representation curve was drawn using only average value of all folds for better comparison. Figure 13. Test results for different representations

84**(TPR: True Positive Rate, FPR: False Positive Rate).**

(a) FMR&FNMR representation; (b) ROC curves. (a) 1 0.8

33**0.6 TPR 0.4 0.2 0 0 0.2 0.4 0.6 0.8 1 FPR (b)**

As can be seen in Figure 13, the

1**proposed system performs the tasks with** high similarity **measures to the desired values.**

According to the numerical results given in Table 6, the proposed system was found also very successful. The

1**APE, MAE and MAPE values belonging to all test results for each fold of 10-fold cross validation** were demonstrated **in Figure** 14. **Averages of all APEs, MAEs and MAPEs** were **given in Figure** 15. **Figure**

14.

1**Results for APEs, MAEs and MAPEs for each fold.**

(a) APEs for generated faces for each fold; (b) MAEs for generated faces for each fold; (c) MAPEs for generated faces for each fold. APE 10 5 0

38**Fold-4 Fold-5 Fold-6 Fold-7**

15 APEs of generated faces for each fold Fold-3 Fold-1 Fold-2 1 2 3 4 5 6 7 8 9 10 11 12 No of test people

60**Fold-8 Fold-9 Fold-10**

(a) MAEs of generated faces for each

54**fold Fold-1 Fold-2** MAE 0.05 **Fold-3** 0.03 **Fold-4 Fold-5** 0.00 **Fold-6 Fold-7**

1 2 3 4 5 6 7 8 9 10 11 12 No of test people

60**Fold-8 Fold-9 Fold-10**

(b) MAPE MAPEs of Generated Faces for Each Fold 0.20 Fold-3 Fold-1 Fold-2 0.10 0.00

38**Fold-4 Fold-5 Fold-6 Fold-7 Fold-8**

1 2 3 4 5 6 7 8 9 10 11 12 No of test people Fold-9 Fold-10 (c) Figure 15 Averages of APEs, MAEs and MAPEs. (a) Averages of APE values of generated faces for each fold; (b) Averages of MAPE and MAE values of generated faces for each fold. Mean APE values 10 7 4 1 2 3 4 5 6 7 8 9 10 Fold numbers of 10-fold cross validation (a) Mean MAPE and MAE values 0.10 0.05 MAPE MAE 0.00 1 2 3 4 5 6 7 8 9 10 Fold numbers of 10-fold cross validation (b) Table 6. Numerical results for comparison. Maximum Mean Minimum APE 9.60953 7.68515 6.44791 MSE 0.00067 0.00038 0.00053 SSE 1.40740 0.79380 1.12700 MAE 0.01905 0.01718 0.01482 MAPE 0.05460 0.04367 0.03664 For more realistic and comprehensive

evaluation, all test results at each fold were illustrated in Figure 16 with the desired values as used in the qualitative assessment method. Dark and light lines in the figure represent the desired and the generated face features, respectively. The number of rank orders in

72**10-fold cross validation with** 20 participants as **the results of the**

qualitative assessment method was given in Table 7. Figure 16. Results for 10 different test data sets. (a) The first 10-fold cross validation technique (b) The second 10-fold cross validation technique (c)The third 10-fold cross validation technique (d) The fourth 10-fold cross validation technique Figure 16. Cont. (e) The fifth 10-fold cross validation technique (f) The sixth 10 -fold cr oss validation technique (g) The seventh 10-fold cross validation technique (h) The eighth 10-fold cross validation technique (h)Theeighth10-foldcro Figure 16. Cont. (i)The ninth 10-fold cross validation technique (j) The tenth 10 -fold cross validation technique Table 7. Number of rank orders in 10-fold cross validation with 20 participants. Rank Levels No of 10-folds 1 2 3 4 5 The first 0 0 0 4 16 The second 0 0 2 11 7 The third 0 0 6 4 10 The fourth 0 1 3 5 11 The fifth 0 1 2 8 9 The sixth 0 3 5 10 2 The seventh 0 0 2 7 11 The eighth 0 0 4 6 10 The ninth 0 0 5 10 5 The tenth 0 0 0 6 14 Total 0 5 29 71 95 All observers who participated in our qualitative assessment method

39**had normal (20/20) or corrected to normal acuity, normal color vision, and no history of ocular pathologies.**

In the qualitative assessment method each of the participants has

2**assigned a numerical value of 1, 2,** 3, 4 **or**

5 for all results of the each fold. Thus, within each condition, the system results were assigned 200 values (ten values

2**per participant). In order to carry out a meaningful quantitative analysis, the rank frequency, that is, the number of times**

2**was assigned a rank value (i.e., the number of all the ones, twos, threes,** fours and fives **for** the results), **was taken as the operational definition of perceived** result **quality for**

each fold.

2**For each condition, the rank frequency** was **summed across the**

10-folds, which resulted in the

2**summed rank frequency (refer to** line **"Sum" in**

Table 7). From Table 7, it is clear that the proposed system

2**was assigned the highest number of**

fives for all folds of

1**10-fold cross validation technique.** According to **the** means **of** qualitative assessment method, **the** proposed **system**

produced high quality results that were perceived to have the highest marks. Comparison for the folds of 10-fold cross validation technique can be also achieved using Table 7. According to Table 7, the first fold of the system was perceived to have the highest marks, tenth fold of the system

2**produced imagery that was assigned the** second **highest number of** fives **(i.e., essentially perceived as „second best"); and the**

seventh fold of the system

2**produced imagery that was assigned the** third **highest number of** fives **(i.e., essentially perceived as**„third **best").** For each condition **the**

rank frequency was summed across the all folds

86**of 10-fold cross validation** technique. Total value **of the** table indicates **the**

sum of the marks for the all test results. It actually shows the overall system performance from point of the subjective manner. According to the total value, 47.5% of the participant gave 5, it means that they thought that "the results are nearly the same with the desired values, the system is"; 35.5% of the participant gave 4, it means they thought "the results are very similar to the desired values, the system is successful", 14.5% of the participant gave 3, it also means that they thought "the results are similar to the desired values, the system success is average" and 2.5% of the participant gave 2, it means they thought "the results are a bit similar to the desired values, but the system cannot be accepted successful". None of the participant gave 1, so no of them thought that the system is failed. All obtained results from the two different evaluation platforms

1**for each fold of 10-fold cross- validation technique**

have strongly demonstrated and clearly confirmed that there are close relationship among faces and fingerprints. Based on the results reported in this article in various forms, it can be clearly and confidently to declared that the proposed face model generation

1**system is very successful in** achieving face parts **from only fingerprints.**

The system presented in this paper is a complete system combining all the other recent works introduced in [5-13], and it provides more complex and distinguished solution for generating the face parts. To the best of our knowledge, investigating relationships among fingerprints and face features including the all face parts has not been studied in the literature so far. Also it is the first study that was evaluated with 10-fold cross validation technique with qualitative evaluation metrics in addition to the quantitative evaluation metrics.

1**Taguchi experimental design technique was** also **used to** obtain best ANN **parameters**

for better performance. Extensive experimental results have shown once more that the proposed system yields superior performance and it is capable of efficiently generating the face masks from only fingerprints. 9. Conclusions and Future Work Predicting complete face features with high accuracy just from fingerprints is the principal objective of this paper. In

98**this study a** novel **approach was developed,** used **and**

introduced to successfully achieve this aim. In the proposed study, the relationships among fingerprint and face biometrics were established and an unknown biometric feature was also predicted with high accuracy from a known biometric feature. The results of the two main validation tests proved

1**that the proposed system is very successful in** automatically generating the **faces from only fingerprints.**

This study is an improved version of our earlier studies. In the future research, investigations will be conducted to enhance the face generation process. In addition, a larger multi-modal database with international participants including Fs&Fs will be collected to investigate the proposed approach. Even if

1an unknown biometric feature can be achieved from a known biometric feature, the

achieved feature cannot represent faces in real time face pictures. This initial study might help to

1lead to create new concepts, research areas, and especially new applications in the field of biometrics. Comparing with the results given in the

literature

89determining the best parameter settings by Taguchi experimental design

technique has improved the results significantly. In addition, it should be noted that predicting more face parts from fingerprints reduced the prediction performance of the system.

1For a more objective comparison, the performance and accuracy of the system have been evaluated

with 10-fold cross validation technique using qualitative evaluation metrics in addition to the expanded quantitative evaluation metrics. Consequently, the results were

1presented on the basis of the combination of these objective and subjective metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.

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AN INTELLIGENT AND

8**AUTOMATIC FACE** SHAPE **PREDICTION SYSTEM FROM FINGERPRINTS**

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ss@gazi.edu.tr, neclaozkaya@erciyes.edu.tr ABSTRACT

7**—This paper presents an intelligent system for generating face shapes from only fingerprints without knowing any information about faces. The**

7**proposed system based on artificial neural network has got a**

number of modules including two biometric data acquisition

1**modules, two feature extraction modules, an** artificial neural network **module, a** face re-construction **module and a** test & evaluation **module.**

Experimental

1**results have shown that the** faces **can be successfully generated from only fingerprints.**

Although the proposed system is an initial study, the performance of the system is very promising for the future developments. Key Words: Intelligent systems, biometrics, artificial neural networks. 1. INTRODUCTION Biometrics is a well known technology and deeply studied research field especially to support reliable personal identification systems. Recently, most of the works in this area have focused on improving the accuracy and processing time of the biometric-based systems. For achieve this improvement more effective, fast and robust techniques have been developed [1]. Obtaining

18**a biometric feature of a person from another biometric feature of the same person**

is a challenging idea and it is a useful transformation for many applications. There has been no study on

1**investigating relationships among the biometric features or obtaining one feature from** another except **the**

authors have recently reported in the articles [2]-[10] for the first time. The

1**authors proposed novel approaches for generating the face borders** [2], **the face contours including face border and ears** [3], **the face models including eyebrows, eyes and mouth** [4], **the inner face parts including eyes, nose and mouth** [5], **the face parts including eyes, nose, mouth and ears** [6], **the face models including eyes, nose, mouth, ears and face border** [7], **the face parts including eyebrows, eyes, nose, mouth and ears** [8], **only eyes** [9] **and the face parts including eyebrows, eyes and nose** [10] **from only fingerprints without any need for face information or images.**

The results in the articles have clearly demonstrated

1**that an unknown biometric feature can be achieved from a known biometric feature.**

309 Some biological and physiological evidences were motivated to us to investigate the relationships among fingerprints and faces. These evidences can be explained as follows:

1**It is known that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment** [11]. **Physical appearances of faces and fingerprints are also a part of an individual's phenotype.**

4**In dermatoglyphics studies, the maximum generic difference** in **fingerprints has been found among individuals of different races** [11]. **Unrelated** people **of the same race have very little generic similarity in their fingerprints; parent and child have some generic similarity as they share half** of **the genes, siblings have more similarity and the maximum generic similarity is observed in the identical twins, which is the closest genetic relationship [12].**

This similarity distribution is very similar for faces of the people. The general characteristics of fingerprints and faces were determined by the genes [11]. These truths have indicated

1**that there** could **be some relationships among** biometrics. **In order to investigate** and support **this assumption an intelligent** face prediction **system**

from only fingerprints has been developed and introduced in this study. 2. OVERVIEW OF BIOMETRICS A biometric system operates its task

11**by getting biometric data from a person, extracting a feature set from the acquired data and comparing this feature set against the template** feature sets **in the database**

[13]. The most used biometric systems are Automatic Fingerprint Identification Systems (AFISs) and Automatic Face Recognition Systems (AFRSs). Good surveys about these techniques were given in [1] and [14], [15], respectively. This study focuses on fingerprints and faces (Fs&Fs). To acquire feature sets of Fs&Fs in the literature, feature-based approaches have been mostly used. In the feature-based AFISs,

1**two important attributes including end points and bifurcations**

were used [1]. Feature-based AFRSs mainly consist

1**of three steps. These steps cover detection** and localization **of the faces,**

feature extraction and finally recognition tasks [16]. Both fingerprint and face recognition processes are really complex and difficult tasks [1], [14] and [16]. Recently, multi-modal biometric systems (MMBS) have gained

1**acceptance among designers due to their performance superiority over the** uni-modal **systems that have some limitations about accuracy, processing time and vulnerability to spoofing**

[15].

1**Detailed information about MMBSs can be found in [13]**

and [17].

1**3. ARTIFICIAL NEURAL** NETWORKS **Artificial Neural Networks** (ANNs) **have been applied to solve many problems**

[1],

25**[14], [18]-** [20]. **Learning, generalization, less data requirement** and **fast computation**

1**features have made ANNs very attractive for applications** [18]. **These fascinating features have also made them popular in biometrics**

[1]-[10], [14], [19] and [20]. Multilayered perceptron (MLP) structure was used in this study. The

22**MLP consists of three layers: Input, output and hidden layers.**

The

2**neurons in the input layer can be treated as buffers and distribute** xi **input signal to the neurons in the hidden layer. The output of** the **each neuron** yj **in the hidden layer is obtained from sum of the multiplication of all input signals** xi **and weights** wji **that follow all these input signals. The**

2outputs of the neurons in other layers are calculated in the same way. The weights are adapted with the help of a learning algorithm according to the error occurring in the calculation. The error can be calculated by subtracting the ANN output from the desired

output [18]. There have been many learning algorithms to train ANNs. The scaled conjugate gradient (SCG) algorithm is one of them. It is based on conjugate directions and adjusts the weights of ANNs [23]. 4. AUTOMATIC FACE SHAPE PREDICTION SYSTEM FROM FINGERPRINTS Unlike to the previous studies [2]-[10], the proposed

1ANN based intelligent system generates the face shape including eyes, mouth and face border of a person from only one fingerprint of the same person. The architecture of

the developed Fingerprint to Face Shape Generation System (FP2FSPS) covering main modules is given in Figure 1. Implementation steps of the FP2FSPS to establish a relationship among fingerprints and faces (Fs&Fs) can be mentioned as follows: 1. A real multi-modal database was established from Fs&Fs. 2.

1Feature sets of Fs&Fs were obtained. 3. Training and test data sets were

established. 4. Suitable ANN structure and its optimal parameters were determined. The ANN structure is finally established. 5. ANN based FP2FSPS was trained to generate face shapes more realistically until achieving certain accuracy in learning. 6.

2In order to test and evaluate the accuracy of the FP2FSPS, the test results were

compared against to a variety of state-of-the-art methods [1]. Biometric Data Acquisition Modules

1Feature Extraction Modules ANN Module Test & Evaluation Module Face Re-construction Module

Figure 1. Architecture of the FP2FSPS Biometric data acquisition

1modules help to store biometric data of individuals into the system database.

1A real multi-modal database that includes Fs&Fs belonging to 120 people was established.

Only a frontal face image and a fingerprint that was

1index finger of the right hand were used in this study.

An example of biometric feature set in the database is given in Figure 2. Figure 2. An example for F&F set in the multimodal database The feature extraction modules extract the discriminative feature sets from the acquired biometric data.

1Fingerprint feature sets were computed using a SDK developed by Neurotechnologija

[21]. The reason of this preference is to establish an objective assessment for face shape prediction via the FP2FSPS.

1To obtain the feature sets of faces, a feature-based face feature extraction algorithm was borrowed from Cox et al. [22] and it was fundamentally modified and adapted to this application. In comparison to the approach proposed in [22], increasing the number of the reference points from 35 to

53 points

2helped to represent the faces more accurately and sensitively. In addition, face feature sets were shaped from x-y coordinates of the face reference points, not distances or average measures as in [22]. The

ANN module that was

1used to analyze the existence of any relationship among Fs&Fs was implemented with the

1help of 3-layered MLP structure that was trained with SCG algorithm. The SCG algorithm adjusts the

weights and biases of the ANN according to its learning strategy. The details of SCG algorithm was given in [23]. The

1ANN module is the most critical and important module of the system. Because, all other modules

1are on duty, either in pre-processing or post-processing of this main process. The

1training process is started with applying the feature sets of Fs&Fs to the system as inputs and outputs,

2respectively. The system achieves the training process with these feature sets according to the learning algorithm and the ANN parameters.

1Even if the feature sets of Fs&Fs are required in training, only fingerprint feature sets are used in test.

The

1outputs of the system for these unknown test data indicate the

2success and reliability of the system and it must be clearly shown by evaluating the ANN outputs against to the proper metrics.

The traditional metrics of an ordinary biometric system

2are no longer appropriate to characterize the performance of the

FP2FSPS. So, in addition to the ROC curve, the results of the system are evaluated by considering the following numerical metrics:

1mean squared error (MSE), sum squared error (SSE), mean absolute error (MAE), absolute percentage error (APE) and Mean APE.

APE is the measure of accuracy of the system as a percentage for a test face. MAPE shows mean APE that is

1average of the absolute percentage errors per each coordinate of the feature sets of the faces.

Similarly,

1**MAE is an average of the absolute errors per each** coordinate **of the feature sets of the faces.**

These metrics were explained in [24].

1**To evaluate the system results comprehensively a visual evaluation platform** was also **created by drawing the ANN outputs and** their **desired outputs in the same** page as overlapped. **In order to achieve the visual evaluation effectively, a face re-construction module was developed**

1**to convert the ANN outputs and desired outputs to visual face**

shapes.

1**Consequently, for a more objective comparison, the performance and accuracy of the system have been evaluated and presented on the basis of the combination of these metrics for illustrating the qualitative properties of the proposed methods as well as a quantitative evaluation of their performances.**

5. EXPERIMENTAL RESULTS The proposed FP2FSPS discussed in previous section was implemented to conduct the experiments efficiently. The dedicated and developed software supplies

1**all of the system parts to be controlled properly. The**

experimental data

1**sets used in the test contain only** feature sets **of** fingerprints of **the test people.**

The face feature sets of these people were never used in training processes of ANN. They were used for evaluation of the system performance. The

1**inputs and the outputs of the system were vectors sized** 298 **and** 106, **respectively. Producing** the faces **as close to the real one as possible is critical for this study.**

The metrics MSE, SSE, mean APE, mean MAE and mean MAPE were 0.00044, 1.90770, 4.29903, 0.01572 and 0.04056, respectively. The

23**ROC curve of the** test results **is** given **in Figure 3. ROC**

1 0.8 0.6 TPR 0.4 0.2 0 0 0.2 0.4 0.6 0.8 1 FPR Figure 3. ROC curve of the test results

24**(TPR: True Positive Rate, FPR: False Positive Rate)** According **to**

the test results the

2**proposed system performs the tasks with high similarity measures to the desired values.** For **the**

purpose of more realistic and visual evaluation, all of achieved

1**test results and desired values of them have been drawn** on **the same platform** as shown **in Figure**

4. Dark continuous

2**and light** dashed **lines in the figure represent the desired and the generated face features, respectively.**

In addition, to show the overall system performance graphically,

1**APE, MAE and MAPE values belonging to all test results**

were demonstrated in Figure 5. Based on the results and observations, the presented FP2FSPS can be used as an intelligent model to predict face shapes from fingerprints, effectively. 6.

21**CONCLUSION AND FUTURE** WORKS **The** principal objective **of this paper is to** generate automatically **the**

2**face shapes including eyes, mouth and face border**

from only fingerprints with high accuracy. This article successfully presents an approach to predict face shapes from only fingerprints. The relationships among biometrics and achieving

1**an unknown biometric feature from a known biometric feature**

are also experimentally shown in the proposed study. When each of the results was visually elaborated, it is very clear to see that there are very close matches among ANN outputs and their desired values. The results presented in this work reports that there are more than twelve close matches considering mouths and face borders and also more than fifteen close matches at eyes. The experimental results provided very encouraging and successful results in achieving the face shapes from fingerprints automatically. These results

1**confirmed once more that there are** close **relationships among Fs&Fs. It is expected that this study will lead to create new concepts, research areas, and especially new applications in the field of biometrics and forensics.**

In future studies,

2**investigations will be conducted to enhance the face generation**

processes. It is also studied on modeling the relationships among Fs&Fs to prove not only experimentally but also mathematically. In addition, the performance and accuracy of the system should be shown by using a larger multi-modal database including biometric features of people from different countries. Figure 4. Representing the test faces achieved from the FP2FSPS and their desired values. 7.

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(a) APE Values (b) MAE and MAPE Values Figure 5. Error values for generated faces.

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