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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.

82**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. 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

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

[1, 2].

29**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

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

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

1**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

1**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]

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**

1weights 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,

1Taguchi 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

4is a well-known and robust design

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

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

4ensures the reproducibility of the experimental results and

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

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

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

executed. 3. Mean

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

are analyzed and used. The results from the experimental

53runs 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.

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

1**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].

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

1**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

1**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

1**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].**

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

1**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

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,

1training 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

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

59main effects plot for SNR that is given in Figure

6. In this work, the

59main effects plot for SNR has confirmed that the

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

1layers 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

1Layers 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

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

3This 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 :

3Compute $\nabla f(x0)$ and $h0 = \nabla f(x0)$ 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 :

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

22 hi−1

30is 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

1ANN 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

1system 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

1must 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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