An Intelligent and Automatic Eye Generation System from Only Fingerprints
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Abstract — Identifying people using body measurements has been devised and practiced for a century. Although biometrics is a deeply studied field within the last three decades, relationships about biometrics have not been studied so far. In this study, we have focused on investigating the existence of any relationships between fingerprints and eyes. We have also strived to generate the eyes of a person using only fingerprint of the same person without knowing any information about eyes. Consequently, we have produced and introduced a new, automatic and intelligent system using a novel approach based on artificial neural networks to generate eyes from fingerprints among 0.4 % and 1.56 % absolute percent errors. Experimental results have shown that fingerprints and eyes are related to each other closely.

Keywords — information security, biometrics, artificial neural networks.

I. INTRODUCTION

There is an increased emphasis on the privacy and security of information recently. Biometrics is a marvellous technology that covers the unrealistic performance expectations compared with the existing alternatives like PINs and passwords. Biometric features are reliable as far as not being transferable easily, peculiar to individual as much as it represents him/her with his/her physical or behavioral attributes and invariant from beginning to end of the life. Since biometric based recognition systems has been largely investigated for 30 years, a lot of robust techniques and effective algorithms that present accurate security solutions are designed and proposed. In spite of all these developments in biometrics, there is no study on investigating relationships among the biometric features or obtaining one feature from another. We have noticed that most of the efforts in biometrics have been focused on how to improve the accuracy and processing time of the biometric systems, to design the more intelligent systems, and to develop more effective and robust techniques and algorithms [1], [2]. The scope of our study is intended to develop an automatic and intelligent system capable of obtaining eyes from fingerprints without having any priori knowledge about eyes. In order to achieve that, an intelligent eye generation system from fingerprints (fingerprint to eyes: F2E) has been developed and introduced in this study. Although this research is in the biometrics field, it spans several disciplines such as image processing, pattern recognition, artificial intelligence, privacy and security, verification systems, soft computing and artificial neural networks.

This paper is organized as follows. Section 2 briefly describes background information on biometrics, automatic fingerprint identification and verification systems (AFIVSs), face recognition systems (FRSSs) and artificial neural networks (ANNs) respectively. Section 3 highlights the novelty of the proposed technique, presents basic notation, definitions, performance metrics related to the F2E and explains the various steps of the new approach. Section 4 demonstrates our experimental results. Finally, the proposed work is concluded and discussed in Section 5.

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II. BACKGROUND

Fingerprints are the most widely used biometric features due to their uniqueness, immutability and reliability [3]. The AFIVSs might be broadly classified as being minutiae-based, correlation-based and image-based systems [4]. A good survey about these techniques was given in [1]. In our study to get feature sets of the fingerprints a minutiae-based approach that relies on the comparisons for similarities and differences of local ridge attributes and their relationships to make a personal identification [5], [6], [7] has been preferred. Therefore details of the minutiae-based approach are given in this paper. The minutiae-based approach attempts to align two sets of minutiae from two fingerprints and count the total number of matched minutia. In these approaches firstly it is extracted the minutiae from the fingerprint images correctly; then the comparison between two fingerprints is made using the two sets of minutiae parameters [4]. In general the comparison is based on representing two important attributes including end points and bifurcations. These main ridge characteristics are local discontinuities in a fingerprint image. 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 [2], [5]. 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, then these local attributes will also become
rotation, translation and scale invariant [8], [9]-[11]. Core points are the points where the innermost ridge loops are at their steepest. Delta points are the points from which three patterns deviate [10], [12], [13]. Many algorithms have been proposed to compute the singular points and orientation information of a fingerprint. The general methods to detect the singular points are poincare-based methods [14], intersection-based methods [10] or filter-based methods [15]. Ridge valley structure of a fingerprint image and local and global features which are used in minutiae-based AFIVSs are given in Fig. 1.

![Fig. 1. Ridge valley structure and features of a fingerprint.](image)

Main steps of the operations in 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, properly representing the fingerprint images with their feature sets, recording the feature sets into a database, matching the feature sets, testing and evaluating the system [16]. 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 more affect the performance. In the correlation-based AFIVS, global patterns of the ridges and valleys are compared to determine if the two fingerprints align. The template and query fingerprint images are spatially correlated to estimate the degree of similarity between them. The performance of the correlation-based techniques is affected by non-linear distortions and noise present in the image. In general, it has been observed that minutiae-based techniques perform better than correlation-based ones [17]. In the image-based approaches, the decision is made using the features that are extracted directly from the raw image that might be the only viable choice when image quality is too low to allow reliable minutiae extraction [4].

Faces are probably the most common biometric characteristics used by humans to make personal recognition. Face recognition technology is well advanced. Because it is an active area of research with applications ranging from static, controlled mug-shot verification to dynamic, uncontrolled face identification in a cluttered background [5]. 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 [18]. Face detection is a necessary first-step in face recognition systems, with the purpose of localizing and extracting the face region from the background. It is a complex problem and many comprehensive face detection approaches have been proposed in the literature [19]. Face detection and 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. [20]. In addition to these varying factors, lighting, background, scale, noise and face occlusion and many other possible factors make these tasks even more challenging [18]. The most popular approaches to face detection and recognition [21] are based on either the location and shape of the facial attributes, such as the eyes, eyebrows, nose, lips and chin and their spatial relationships or the overall analysis of the face image that represents a face as a weighted combination of a number of canonical faces [22]. Also many effective and robust methods for the face recognition have been proposed [2], [5], [18]-[21], [23], [24]. As it has been mentioned before the aim of this study is establishing a relationship between eyes and fingerprints and generating the eyes from fingerprints with no knowledge about them. For this purpose to get the feature sets of the eyes a feature-based manual approach has been preferred [25] from the face recognition literature. We can explain the reason of this preference is that we used a minutiae-based approach 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 fingerprints and eyes should be obtained in the same way. So, we decided to use feature-based approach to get the feature sets of the eyes. Cox et al. [25] used a template that was shaped from manually extracted 35 points for representing the each faces. They also used a dimensional feature vector computed from these points. We have increased the number of the eye reference points from 5 to 10 points for each eye for more accurate and sensitive representation. Also our eye feature sets are shaped from x-y coordinates of the eye reference points not distances or average measures as in [25]. Their method needs these modifications to use in our study. Because the feature sets do not contain enough information about eyes to re-generate the eyes properly. Therefore we have increased the number of the points and we used the coordinates of them simply. Our feature sets contain enough information about eyes for getting them again with high sensitivity.

III. PROPOSED INTELLIGENT AND AUTOMATIC EYE GENERATION SYSTEM FROM ONLY FINGERPRINTS

Fingerprint and face recognition topics have received significantly increased attention from both the academic and industrial communities as two of the few biometric methods that possess the merits of their reliability, performance and high accuracy. Proposed F2E that generates the eyes of a person from only fingerprint of the same person without having any information about the eyes will be very interesting innovation to the biometrics arena as a first step for an intelligent and automatic face generation system from only fingerprints. Also it will facilitate face recognition, security applications and police works. Implementation steps of the F2E to establish a relationship among fingerprints and eyes
(Fs&Es) can be mentioned as follows: A real multimodal database (MMDB) that includes Fs&Es belonging to 120 people was established. Fingerprint feature sets were obtained from the fingerprints. Enhancements, binarization, thinning, and feature extraction processes were applied to the acquired fingerprints to achieve this process. Eye feature sets were obtained from the eyes. The eyes were represented by 20 points. Training and test data sets were established to train and test the ANN predictors in the F2E. The training sets included pairs of Fs&Es while the test sets included only fingerprints. Eye feature sets of the test people were used in the evaluation process as the desired outputs. 80 data sets covering pairs of Fs&Es were used to train the ANN based F2E. The sizes of the input and the output vectors were 298 and 40, respectively. Suitable ANN structures and training algorithms were selected and parameters of them were determined. F2E was trained to generate eyes more realistically until achieving certain accuracy in learning. The ANN based system tested using 40 test sets covering only fingerprints. In order to test and evaluate the accuracy of the F2E, the test results were compared against a variety of state-of-the-art methods [1].

F2E basically consists of a data enrolment module, a feature extraction module, an ANN module, a test & evaluation module and an eye reconstruction module. These modules are explained below. The first module of the system which is called the data enrolment module helps store biometric data of individuals into the biometric system database. During this process, Fs&Es of an individual have been captured to produce a digital representation of the characteristics. Two types of data are used in this study: Fs&Es. The second module of the system, extracts discriminative feature sets from the acquired data. Extracting local and global feature sets of fingerprints is achieved. This process includes fingerprint singularities, minutiae points and their parameters. Similarly feature sets of the eyes are obtained. The ANN module is used to analyze the existence of any relationship between Fs&Es. The ANNs have been applied to solve many problems [26]-[30]. Learning, generalization, less data requirement, fast computation, ease of implementation and software & hardware availability features have made the ANNs very attractive for biometric applications [23], [28]-[30]. Multilayered perceptron (MLP) is one of the most popular ANN architectures. Because of the MLP structure can be trained by many learning algorithms, it has been successfully applied to a variety of problems in the literature [27]. The ANN part of the system has been implemented with the help of the MLP structure that is trained with scaled conjugate gradient algorithm to find out any relationship between Fs&Es. The details of the scaled conjugate gradient algorithm can be found in [31], [32]. The ANN module can be encapsulated as an automatic and intelligent translator in which fingerprint images are converted to eye shapes efficiently. The ANN module is 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 that is done by the ANN module. So, if we investigate this module deeply, we can explain the working principles of the F2E properly.

Pre-processing steps include enrolling the Fs&Es to the system, extracting their feature sets in proper format, and arranging them in a suitable form that is convenient to the ANN module as an input or an output. Post-processing steps include the reconstruction of the eyes from feature sets which were obtained from the ANN and the evaluation process of the system. The ANN module operates its task in two stages: the training and the testing. In the training process, randomly selected input-output image sets covering Fs&Es belonging to the same people were used. The ANN structure and the training parameters were determined for achieving the training stage accurately. The training process is started by applying a person’s fingerprint feature set to the system as an input and same person’s eyes feature set as the desired output. The system achieves the training process with these feature sets according to the learning algorithm and the ANN parameters. Both Fs&Es feature sets are required in the training. Only fingerprint feature sets are used to obtain the eyes in the test. These fingerprints are unknown biometric data for the F2E. The outputs of the system for these unknown data indicate the success and reliability of the system. This success and reliability of the system must be shown clearly by evaluating the ANN outputs against to the proper metrics in proper way as it has been used in the literature. The block diagram of the ANN module is given in Fig. 2.

![Fig. 2. The block diagram of the ANN module](image-url)

In ideal situation, it is expected to that a biometric-based recognition system will take the correct decision when a biometric feature is presented to the system. However in practice a biometric system cannot be able to make perfect match decisions at all time. It can make two basic types of errors: (1) False Match Rate (FMR): In the case of identification or screening, the biometric system incorrectly declares a successful match between the input pattern and a nonmatching pattern in the database. In the case of verification the pattern associated with an incorrectly claimed
identity. (ii) False Non-match Rate (FNMR): In the case of identification or screening, the biometric system incorrectly declares failure of match between the input pattern and a matching pattern in the database. In the case of verification the pattern associated with the correctly claimed identity [33]. These traditional metrics of an ordinary biometric system are no longer appropriate to characterize the performance of the F2E. As it has been explained earlier, the aim of this study is to create eye shapes from only fingerprints without any information about eyes. Under these conditions, the system can not be evaluated properly with metrics of an ordinary biometric authentication system. So, we have decided to use appropriate performance metrics in this study. The results of the system may be evaluated by considering the following metrics: Mean squared error (MSE), sum squared error (SSE), average correlation, absolute percent error (APE) [34] and mean APE. In addition to these numerical evaluations a visual evaluation platform is created by drawing the ANN outputs and the desired outputs in the same sheets. Also another visual evaluation platform is presented by drawing the ANN outputs on the involved real face images of the test people. 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 performance.

Eye reconstruction module facilitates the evaluation process, simplifies to comment on the results and presents to the users a comprehensive evaluation platform for visual sensing. In order to achieve these processes easily and efficiently, an automatic system has been proposed and a graphical interface that provides a mechanism for the system manager to manage the system is developed. This interface supplies all of the system parts to be controlled properly.

IV. EXPERIMENTAL RESULTS
The proposed eye generation system from fingerprints discussed in previous section is successfully implemented. The concept of generating eyes from fingerprints is a novel and challenging idea to biometrics technology. Dedicated software has been developed to conduct the experiments easily and efficiently. In our experiments, an MMDB having Fs&E Es belonging to 120 people was established. In the training processes, 80 of 120 Fs&E Es image sets were randomly selected from our MMDB. The remaining 40 image sets of Fs&E Es were used for the test. The experimental image set used in the test process contains only fingerprint images of the test people and it is an unknown data for the system. The eye image sets of these test people are used for evaluation of the system performance. In the training process inputs and the outputs of the system were vectors sized 298 and 40, respectively. The feature vectors of fingerprints were computed using VeriFinger 4.1 SDK developed by Neurotechnology. The reason of this preference is to establish an objective assessment for the F2E. This software is known as an effective, robust and reliable AFIVS in the field of biometrics and uses a minutiae-based algorithm. Detailed explanation of algorithms, detailed information of fingerprint feature sets and their storage format are given in [35].

Producing the eyes as close to the real one as possible is critical for this study. In order to evaluate the performance of the system effectively, we have benchmarked our system against to the metrics MSE, SSE, APE, average APE, average correlation and human visual evaluation. The metrics MSE and SSE were computed before rescaling, while the other metrics MSE, SSE, average APE and average correlation were calculated after rescaling as 8.5079e-004, 1.3613, 28.6403, 4.5825e+004, 0.973047 and 0.997256 respectively.

These results indicate that the proposed system performs the tasks with high similarity measures to the desired values. For the purpose of more realistic and visual evaluation, test results achieved from only fingerprints were shown in Fig. 3, and Fig. 4. In order to compare the ANN outputs with their desired values, achieved test results and their desired values have been drawn on the same platform in Fig. 3. In a similar way 10 of 40 test results have been drawn on the real face images in Fig. 4. The APE values belonging to all test results were demonstrated in Fig. 5 for showing the overall system performance graphically.
Besides the numerical results indicate the system success clearly, graphical results also confirm this success as well. As it can be seen from Fig. 3, Fig. 4 and Fig. 5, the system is very successful in achieving eyes from fingerprints according to the evaluation metrics. Based on the observations, the proposed system can be used an intelligent and efficient translator that effectively converts fingerprints to eyes.

It is concluded that the fundamental novelty and diversity of the proposed approach over the most other studies in biometrics is that it is the first study that investigates the relationships between fingerprints and eyes. In addition it appropriately generates the eyes from fingerprints without any information about them.

V. CONCLUSION AND FUTURE WORK

The most important objective of this research is to investigate possible relationships between Fs&E and to generate one using another. Consequently an intelligent F&E was designed, implemented and introduced for generating eyes from fingerprints without any need of eye information. In addition the relationships among Fs&E are also experimentally shown. The results indicate for the first time that there are strong relationships among fingerprints and eyes. This is the first step of an automatic and intelligent system that is capable of accurately generating a face with all parts that include eyebrows, eyes, nose, mouth, ears and face border. The concept presented in this work would help to create some new research fields in biometrics in addition to being applied in many fields such as criminal applications.

This approach also would lead to create new concepts, research areas and especially new applications in biometrics field.

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