

Research Article

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Automatic human identification using fingerprint images based on Gabor filter and SIFT features fusion

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Abstract: Today, advancements in science and technology have spurred the rapid evolution of systems like electronic banking, demanding precise, swift, and secure identification of individuals based on their distinct traits. Among these traits, fingerprints stand out as a dependable means of identification, finding application in realms such as crime investigation and national border control due to their simplicity and heightened security. The qualities inherent in fingerprint-based identification have led to its widespread adoption over other identification methods. This article proposes a hybrid biometric system that integrates the Gabor filter and scale-invariant feature transform features and then uses support vector machine and K-nearest neighbors as classifiers, aiming to notably enhance authentication systems by mitigating issues seen in single-method biometric systems. Also, principal component analysis is used to reduce dimensions and eliminate redundancy. In this article, the famous database FVC2004 is used. Test results highlight the considerable reliability and accuracy of the proposed combined approach compared to systems reliant on a singular biometric method.

Keywords: fingerprint, image processing, biometrics, Gabor, SIFT, SVM, K_NN, identification and authentication

1 Introduction

Maintaining the security of confidential information and personal information as well as the ability to securely access them is of particular importance, so defining appropriate solutions for this purpose is very necessary and essential. One of these reliable solutions is the use of physiological features and characteristics, which are called biometrics and have a higher level of reliability and security [1]. In biometric systems, the vital and behavioral characteristics of people are used to recognize their identity. Several vital and behavioral features have been presented for use in biometric-based identification systems. Among the biometrics, fingerprint has been more accepted, for this reason, working on fingerprint images and their proper and optimal processing has been the priority of the activities of specialists in this matter [2,3]. Biometric systems based on fingerprints have important features such as high security, cheapness of fingerprint-taking tools, small size, and ease of working with them. Every person's fingerprint does not change under the influence of mental and emotional events. These characteristics have caused fingerprint-based identification systems to be used more than other identification systems [4]. The use of fingerprints for identification is based on the prominent lines of the first joint of the fingers. Fingertip lines include ridges and depressions, each of these ridges is called a vein, and the empty space between two veins is called a groove. The veins and grooves have a regular structure and a special shape that makes them unique [5]. The quality, transformation, angle, and position of an input fingerprint image are important factors that affect the recognition efficiency in the automatic fingerprint identification system. In general, biometric systems perform identity recognition in two ways: verification or identification. In this thesis, the identification of fingerprints with high accuracy for different fingerprint changes (movement, rotation, extreme changes, pinch, punch) is discussed [6]. In this way, fingerprint identification is done by extracting fingerprint features from fingerprints and comparing these features with

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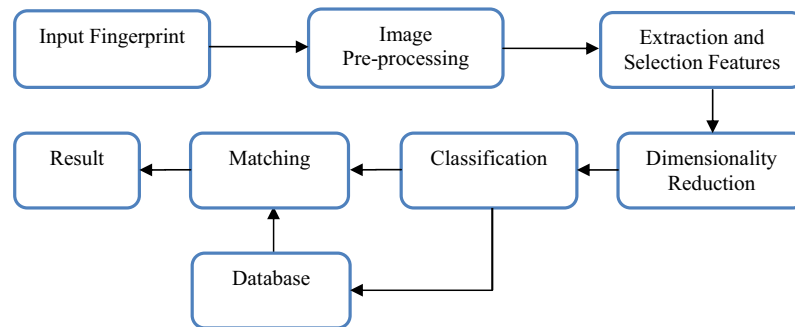


Figure 1: Block diagram human identification using fingerprint images system.

the information already collected in the system. In this research, fingerprint identification by extracting features from the fingerprint areas, in this stage the features the Gabor filter, is used hand in hand with scale-invariant feature transform (SIFT) which is used too. Then the features are combined together and selected of suitable features from them. Also, we used principal component analysis (PCA) to minimize dimensions and eliminate redundancy. In second step the support vector machine (SVM) and KNN classification are used, then merge them together and selection of suitable result from them. In this article, the famous database FVC2004 is used. Figure 1 shows the different stages of the work are fully explained.

2 Literature review

Several studies have been performed on fingerprints in comparison to all other biological characteristics of humans. Compared to other biometric characteristics of humans, fingerprint has advantages that make it unique. The investigation of this issue has been done because nowadays fingerprint recognition has become a necessity. One of the largest identification systems based on fingerprints is the integrated automated fingerprint identification system (IAFIS), which has been used by the police force in the United States since 1999. The IAFIS system currently stores the fingerprint information of more than 60 million people along with the statistical information related to the traces left in the crime scenes and identification with 10 fingerprints to identify the accused in the cases and statistical control in the background.

In 2008, the United States Federal Police began upgrading IAFIS to New Generation Identification systems. In addition to fingerprints, these systems can support other features like palm print, iris, and face [7].

Shen *et al.* used the Gabor filter for the images of hands and FKP. Hamming distance was utilized to match characteristics where the obtained accuracy was 89.20% [8].

The method of feature extraction based on the texture characteristics of knuckle wrinkling images has been investigated and evaluated in terms of efficiency and accuracy [9].

Yin *et al.* suggested a feature extraction method under the name of weighted linear embedding. This method simultaneously uses local and non-local information in the form of Gaussian weighting [10].

Zhang *et al.* presented a new method for extracting different features from ROI images using Gabor filters. In this method, the direction domain information of each pixel is used using Gabor filters [11].

Kang *et al.* [12], on the other hand, presented a new multi-quality biometric system based on non-tangential spectrum of fingerprints, which is claimed to extract three features of fingerprints, knuckles, of finger plates instead of extracting only one feature based on the limitations of single biometrics. The database tested in this method was taken by the authors.

Peralta *et al.* [13] proposed a minutiae extraction method that improves the efficiency of the fingerprint matching algorithm. In this method, the test results have been compared on the FVC database and a database taken by the authors, which are claimed to have high diagnostic accuracy.

In a series of methods, the adaptation of a part of fingerprints was used as a new idea in identifying people's personality. For example, Lee *et al.* describe a partial matching method of fingerprinting using minutia features [14].

Khusnuliawati *et al.* [15] compared SIFT with LEBP for feature extraction using LVQ classifier for the matching process.

Hu *et al.* [16] used a multi-scale uniform local binary pattern block to extract local texture features, followed by

a block-based (2D)2PCA method to preserve local information of finger tissue images.

In 2017 [17], a Gabor filter was used to extract the texture of the finger vein because the Gabor filters can be designed to capture the local orientation and frequency information of the finger vein image. Gabor filters with specific directions were used, with image enhanced to exclude undesirable communities changed them. Subsequently, a post-processing function of morphological top-hat operation was applied to the extracted tissues to further improve the tissue shapes.

In 2018 [18], a new finger muscle dataset was utilized that included videos of muscle structures around the finger. In addition, the performance of different feature extraction algorithms such as maximum curvature, principal curvature, and Gabor filters was compared.

In 2020, Kovač and Marák [19] proposed a passive object recognition system that faithfully combines fingerprints and finger tissue images. For finger tissues, the first of five different steps is performed to perform feature extraction using SIFT and SURF algorithms, while the second is used to detect scale- and rotation-invariant points.

3 General principles in fingerprint recognition systems

Determining the identity of people using fingerprints is widely used compared to other biometric methods of identification. The ridges and depressions in the skin of the fingertip are called fingerprints. The primary factor driving the widespread and common utilization of fingerprints for identification is their inherent uniqueness and permanence throughout an individual's life [20].

The fingerprint, among the oldest and most recognized biometric identification methods for individuals, has significantly evolved in recent years. Current methods have replaced traditional stamps and paper with specialized scanners capable of swiftly verifying and comparing fingerprints against recorded samples. The fingerprint, among the oldest and most recognized biometric identification methods for individuals, has significantly evolved in recent years. Current methods have replaced traditional stamps and paper with specialized scanners capable of swiftly verifying and comparing fingerprints against recorded samples. This method is considered one of the most common methods of identity recognition. So that he is used as one of the safe and fast methods even in employee attendance systems. Fingerprint identification methods ensure consistent and dependable recognition of identity, leading to their utilization

across diverse applications. However, fingerprint identification systems encounter several practical challenges. The elasticity of the skin can cause distortions in the shape and positioning of fingerprints each time they are captured. Besides high reliability and immediate processing, automatic fingerprint identification systems necessitate essential factors for effective operation [21].

To tackle these issues, the essence of forks from fingerprint images should be extracted and matching with the different fingerprints should be investigated. There are standard methods for manual matching of fingerprints, but the manual method of matching fingerprints is difficult and time-consuming and does not have the necessary performance. Of course, since databases have millions of fingerprints, it is practically impossible to match fingerprints manually. To automate the matching, a method for image or coding of fingerprints must be defined. This image expression must have the following conditions: The ability to distinguish each fingerprint at different levels of resolution, simple calculations, the ability to be used in automatic matching algorithms, stability and not changing with noise and damage, being efficient, and showing images in a compressed format. If the image is saved raw, a lot of memory is required and the system will not have the necessary performance.

In structural methods, the features' fingerprints should be firstly extracted from the image and those images are labeled with the matching features, and the matching process is done using these features. So far, 18 features have been identified for fingerprints, the two most important features of which are the end of the ridge and bifurcation of the ridge, which are called Minutiae. The y , x plane and the angles of their protrusions represent the minutia information. Minutiae topological structure is a distinct fingerprint that remains constant with time. Therefore, minutia's topological structure can be matched to facilitate fingerprint detection. A reasonably high-quality fingerprint has approximately 70–80 minutiae; in detailed images, this number naturally drops to 20–30 characteristics; however, fingerprint matching can still be accomplished with this amount.

The majority of fingerprint recognition systems are structured using the minutiae-based system. These two features are shown in Figure 2. Fingerprint recognition can be based on matching the topological structure of minutiae. Most fingerprint recognition systems have a minutiae-based structure. In these systems, there are three basic stages for diagnosis, which are: pre-processing, extraction of minutiae, and adaptation of minutiae [22].

The first step is to focus on leveling the image quality. The second step, extracting image and the last stage is used



Figure 2: Some common minutiae patterns in fingerprints.

for comparison. Regarding the adaptation, there are various methods, among which the following can be mentioned: matching the set of points, graph matching, and isomorphism of two sub-graphs.

Of course, the matching process requires complex calculations for the following reasons: Usually, the fingerprint quality is low. The database of fingerprints is large, and structurally damaged images require powerful matching algorithms.

In the fingerprint recognition systems available in the market, which use these two features (the end of the protrusion and bifurcation of the protrusion), due to the large database and the noise of the images, one-to-one matching is practically difficult, and therefore, a series of matching images are lost. The preparation and then the final adaptation are done by experts.

4 The proposed method of human identification using fingerprint images

In identification systems, the input images are compared with the other images stored in the database. Various reasons, such as noise or the absence of all unique points in the image range, make it difficult to determine an absolute class for all images. One of the complex steps is to improve the image quality and extract details to calculate the direction of the ridge lines of the fingerprint. The existing algorithms are usually known for complex and time-consuming calculations and are performed by software. While the image processing in fingerprint is one of the physical characteristics of this technology. In this research, we

found out the effective features, we found out the method of obtaining the optimal matching score which helps to improve low-quality images.

The biometric system is a pattern recognition system that learns fingerprint images utilizing the extracted features from an image. The feature extraction feature is turned into vector arrays and stored in the database.

In this article, the initial focus is on outlining the biometric system. Among various identification methods, those utilizing physiological or behavioral traits offer heightened reliability and security. Fingerprint identification, a prime example, stands out as the most prevalent and reliable method due to its simplicity and exceptional accuracy. People heavily rely on biometric technology, and the proposed approach involves identifying individuals through fingerprint images. Considering the frequent occurrence of incomplete fingerprint images, there's a necessity to gather more information. The significance of extracting a composite feature lies in determining whether a segment of the fingerprint image is unique to the individual or not. These features are derived by utilizing minutia points and employing skeletal image data. In this method, the Gabor filter and SIFT and their combination were used to reduce noise, and by image processing, data features with more accuracy were extracted. Also, PCA is used to reduce dimensions and eliminate redundancy. Then SVM and K-nearest neighbours (K_NN) classifications are used, matching their results and choosing the best result between them. To check the effectiveness of the proposed method as well as to check the accuracy of fingerprint recognition, the FVC2004 database, each of which contains 91 fingerprints (8 samples of fingerprints from 11 different people), has been used. To evaluate the proposed method, 15 tests were conducted, each time a sample of a fingerprint image was taken. In each stage of implementation, 24 fingerprint samples were examined from the database according to the test steps.

The general scheme of the proposed method is shown in Figure 3.

4.1 Extraction and selection features

The proposed features in this thesis are Gabor filter and SIFT algorithm.

4.1.1 Gabor filter

The grooves and veins in the fingerprint images follow a specific extension locally and are placed next to each other

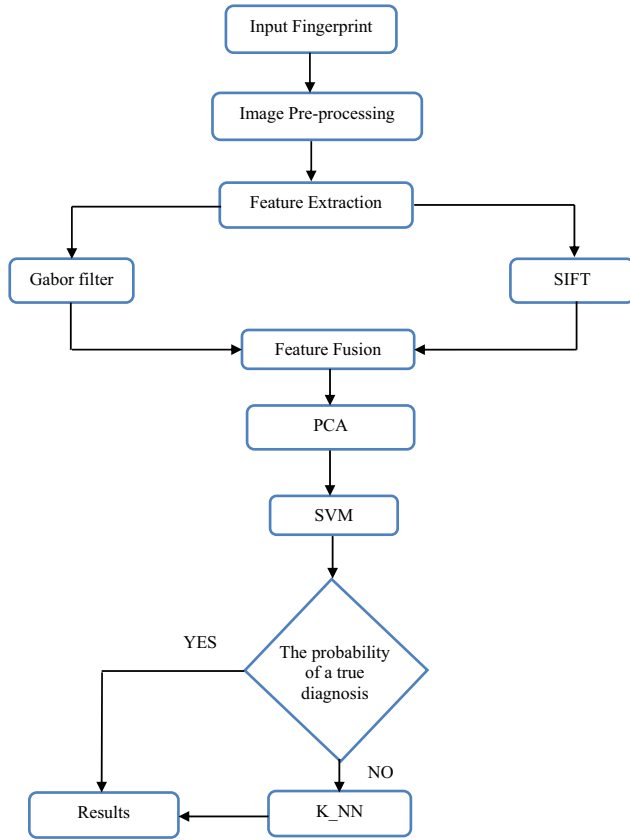


Figure 3: The proposed method.

at a certain frequency. This information is reflected in the direction and frequency of images. To use this data it requires image processing tools rather than machine vision in order to use the fingerprint images properly.

The analysis of the texture of the images will be explained and the analysis of the lines of veins and grooves will be discussed as well.

Gabor function is known as a useful tool in image processing and machine vision, especially in the field of methods based on texture analysis [23]. In 1946, Gabor presented the one-dimensional Gabor function, and then these functions were used in many applications, and the set of two-dimensional filters was first presented by Dogman in 1980. A Gabor filter based on the two-dimensional image domain is defined according to the following formula:

$$G(x, y) = \exp\left(\frac{(x - x_0)^2}{2\sigma_x^2} - \frac{(x - x_0)^2}{2\sigma_y^2}\right) \times \exp(-2\pi i(u_0(x - x_0) + v_0(y - y_0))), \quad (1)$$

which in the formula No. (1) x_0 and y_0 express the desired location in the image and (v_0, u_0) also the modulus that has the frequency $\omega_o = \sqrt{u_o^2 + v_o^2}$ location $\theta_o = \frac{v_o}{u_o}$ and extension

and also deviation σ_x, σ_y . The Gaussian cover standard is shown in horizontal and vertical extensions, respectively. It can be clearly seen that a two-dimensional Gabor filter in a sinusoidal plane in a certain extension and a fraction is modulated by a Gaussian filter. Decomposing the two-dimensional signal leads to a mixed two-dimensional signal, the real part of which is obtained by means of the cosine function modulated with Gaussian and the imaginary part by the sinusoidal function modulated with Gaussian. This type of component is called even symmetric and odd symmetric components respectively [24]. The even symmetric components of the two-dimensional Gabor filter are obtained according to the following formula:

$$g(x, y, T, \varphi) = \exp\left[-\frac{1}{2}\left(\frac{x_\varphi^2}{\sigma_x^2} + \frac{y_\varphi^2}{\sigma_y^2}\right)\right] \cos\left(\frac{2\pi x_0}{T}\right). \quad (2)$$

$$x_\varphi = x \cos(\varphi) + y \sin(\varphi)$$

$$y_\varphi = x \sin(\varphi) + y \cos(\varphi)$$

In these relations, the extension of the Gabor filter and T also shows the alternating function of the C-shaped sine plane. As it is seen, the middle frequency of the filter is found by the sine wave whereas, the filter bandwidth is determined by the Gaussian function. Gabor filters can present an optimal array of signals in two time and frequency domains simultaneously. The fingerprints with the help of Gabor filter banks is based on the assumption that the grooves and streaks of a they create a sine wave pattern. If the angle chosen for the filter is equal to or close to the direction of most of the streaks in the desired area, they will be strengthened, otherwise, they will weaken or make the streaks lighter. In this case, the streaks in the fingerprint image can be strengthened or weakened by appropriate settings of Gabor filter parameters, which is shown in the following formula:

$$E(x, y) = \sum_{u=-\frac{m}{2}}^{\frac{m}{2}} \sum_{v=-\frac{m}{2}}^{\frac{m}{2}} G(u, v, O(x, y), f(x, y)), T(x - u, y - v). \quad (3)$$

In this relation, $O(x, y)$ and $f(x, y)$ show the frequency and extension of the fingerprint lines at their desired point, respectively. To adapt the filter in a stretch to the structure of the lines in the image, the bandwidth of the filter should be adjusted.

4.1.2 SIFT

The SIFT algorithm was invented by David Lowe in 1999 [25]. SIFT is a method for detecting and extracting key

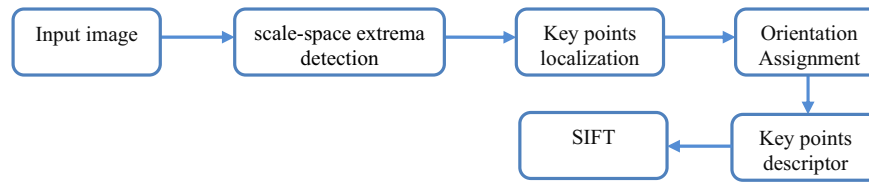


Figure 4: SIFT algorithm.

feature points from images that can be used for applications such as matching between images, object identification, 3D reconstruction of scenes, *etc.* SIFT features are extracted from all images within the database. Subsequently, when presented with a new image, its extracted features are compared against those of all images in the database. The face within the database exhibiting the highest correlation points is identified as the closest match and utilized to isolate the new face. A feature is deemed a match to another feature if its distance falls below a specific fraction compared to the distance of the subsequent closest feature. This challenge arises from the possibility of numerous closely situated features in the event of incorrect matching, stemming from the extensive dimensions of the features. Conversely, in cases of accurate matching, it's improbable to encounter a feature closely situated to others due to its distinctiveness [26]. Figure 4 shows the general block diagram of the SIFT algorithm.

4.1.3 PCA

Due to the high dimensions of the feature space, PCA has been used to reduce the dimensions. This work improves classification accuracy [27,28]. In this method, new coordinate axes are defined for the data in such a way that the first axis is placed in the direction where the variance of

the data is maximum. The second axis is also perpendicular to the first axis and in the direction of maximum variance. In the same way, other axes are also defined. First, a data matrix X is created by the detail coefficients and another matrix by the approximation coefficients of the fourth level, each with dimensions of $200 \times N$. N is the number of beats of all arrhythmias [29]. Then, the average of each column is calculated and subtracted from the signal. Suppose Y is the covariance matrix of X , and A is the matrix of eigenvectors and B is the matrix of eigenvalues calculated from the covariance matrix of Y , and we denote each member of A by ϕ and each member of B by λ , then the matrix of principal components P includes the eigenvectors corresponding to m . The specific value is larger.

$$\lambda_1 > \lambda_2 > \dots > \lambda_m > \dots > \lambda_n, \quad (4)$$

$$P = [\phi_1, \phi_2, \dots, \phi_m], \quad (5)$$

$$C = P \cdot X. \quad (6)$$

Finally, by multiplying the matrix of the main components in the matrix of coefficients whose average is reduced, the feature matrix C is obtained. The first components are selected as features from both depicted matrices. Therefore, 24 components together for each Image form the input feature vector of the classification system.

Figure 5 is shown for two-dimensional data for PCA.

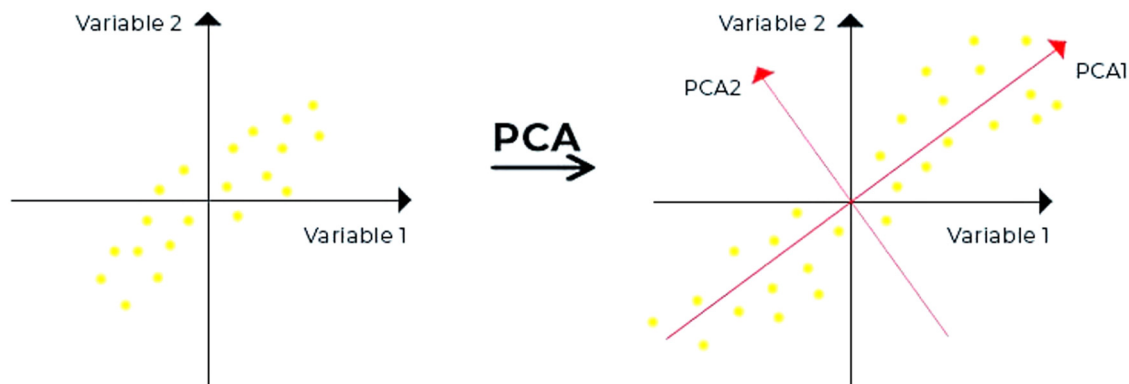


Figure 5: Data distribution in PCA algorithm.

4.2 Classifications

The proposed classifications are SVM and K_NN training classifications.

4.2.1 SVM

This classifier searches for an optimal hyperplane to separate two sets; so that the distance of the closest data becomes the largest possible value. SVM is a supervised classification system; that is, it should be trained by labeled data first [30]. If the data is scattered in such a way that linear separation is not possible, SVM writes the data to a higher dimensional space where linear separation by a hyperplane is possible. Due to the problems of working in high dimensions, a kernel function is used, so there is no need to map data to high dimensions. One of the most common kernels is the radial basis function kernel. SVM is also extended for multi-class separation. The most common multi-class SVM methods are one vs all and one vs one. In these methods, first, several binary classifications are created, and then, their results are combined. For this purpose, using fingerprint images in the database, a training dataset and a test dataset have been prepared. First, with the help of training data, the classifier was trained and then the performance was evaluated by experimental data [31]. Due to the fact that in fingerprints, the patterns of veins and grooves are different, their image matrix is also different from each other. Therefore, according to the image matrix of a fingerprint, it can be distinguished from similar fingerprints. In this method, to avoid comparing two contradictory samples, which is pointless, fingerprints are arbitrarily classified based on existing methods, and SVM is used to detect each class [32]. To better understand the issue, Figure 6 shows data sets divided into two groups, where the best hypersurface is chosen to separate them using the SVM method.

4.2.2 K_NN

One of the most widely used and simple classifiers is the nearest neighbor classifier or K_NN [33,34]. This classifier is independent of probability density estimation and can classify new data separately. In this method, deciding which category a new sample should be placed in is done by examining a number (k) of the most similar samples or neighbors. Among this sample, the number of samples for each class is counted, and the new sample is assigned to the class to which more neighbors belong, most of the neighbors are placed in class X and are attributed [35]. To better

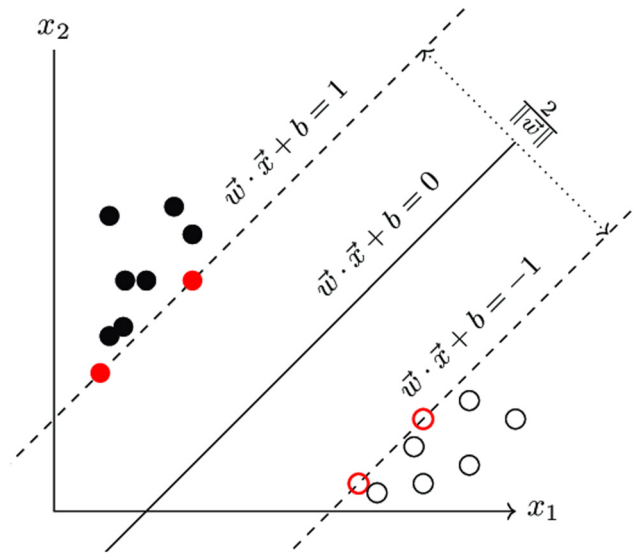


Figure 6: SVM classification.

understand the topic, the distribution of K_NN is depicted in Figure 7.

5 Evaluation of results

In this article, we have gained the characteristics of the features by Gabor filter and SIFT algorithm. For the simulation, the FVC2004 dataset was used. To assess the proposed system and after extracting properties Gabor filter and SIFT were combined, along with the PCA algorithm which was used to reduce unimportant features, then SVM and K_NN classifications were used, matching their results and choosing the best result between them.

It was noticed that the best results of the SVM classification were gained by combining the Gabor filter and SIFT, with a precision of 99.6% and the execution time of 6.4 s, as shown in Figure 8.

Moreover, when the PCA algorithm was used, to suppress unimportant features, which led to improving the results and increasing accuracy and speed in implementation, the SVM classification showed the best performance. It was given by compounding the Gabor filter and SIFT with PCA with a precision of 100% and the execution time of 3.4 s, as shown in Figure 9; the other results are shown in Figures 9 and 10.

Also, the best results for the K_NN classification were obtained by fusing the Gabor filter and SIFT, with a precision of 99.3% and a runtime execution time of 6.3 s, as shown in Figure 10; the other results are shown in the same figure.

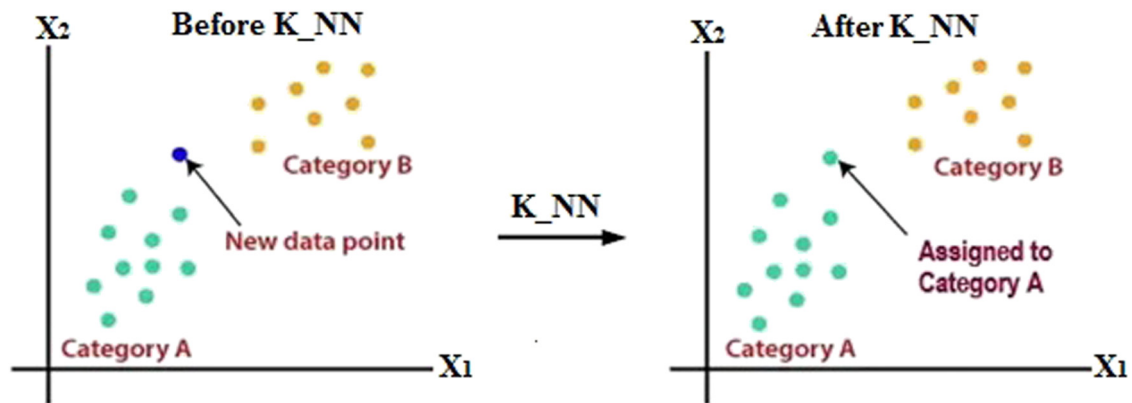


Figure 7: K_NN classification.

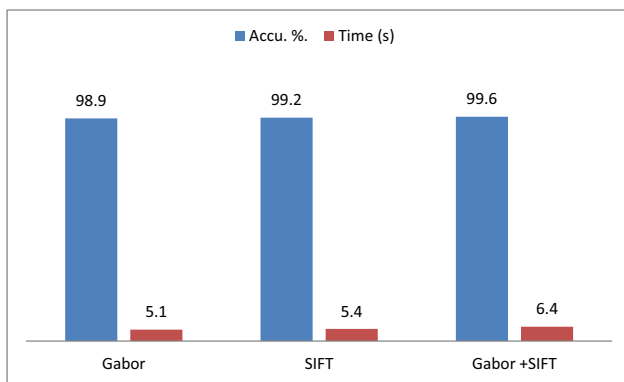


Figure 8: The results with classification (SVM) without using the PCA algorithm.

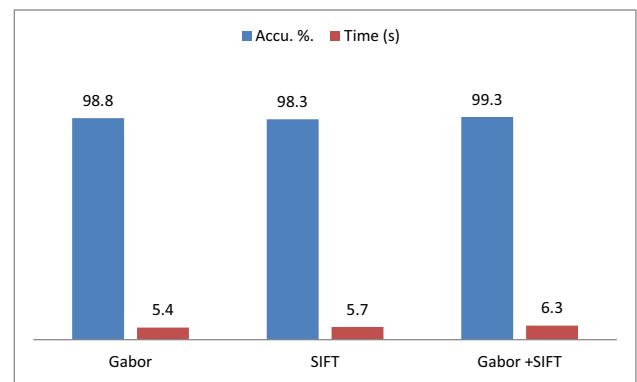


Figure 10: The results with classification (K_NN) without using the PCA algorithm.

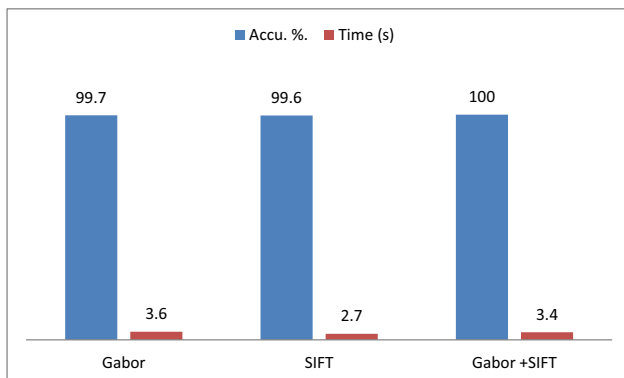


Figure 9: The results with classification (SVM) with using the PCA algorithm.

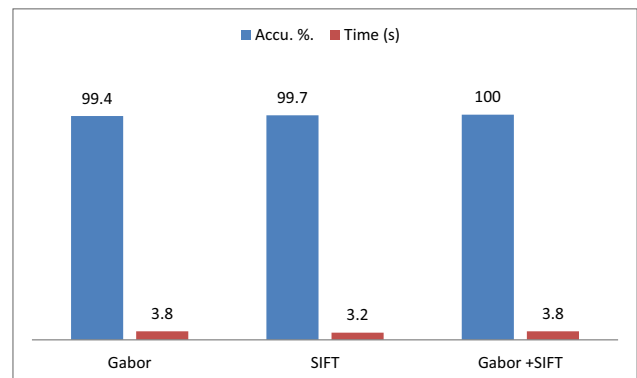


Figure 11: The results with classification (K_NN) with using the PCA algorithm.

On the other hand, the best results of the K_NN classification were obtained by mixing the Gabor filter and SIFT with PCA with a precision of 100% while the execution time

was 3.8 s, as shown in Figure 11; the remaining results are shown in Figures 10 and 11. Tables 1 and 2 show the results of the algorithm in detail.

Table 1: The results with classification (SVM)

PCA Features	Without using the PCA			With using the PCA		
	Gabor	SIFT	Gabor + SIFT	Gabor	SIFT	Gabor + SIFT
Accu. %.	98.9	99.2	99.6	99.7	99.6	100
Time sec.	5.1	5.4	6.4	3.6	2.7	3.4

Table 2: The results with classification (K_NN)

PCA Features	Without using the PCA			With using the PCA		
	Gabor	SIFT	Gabor + SIFT	Gabor	SIFT	Gabor + SIFT
Accu. %.	98.8	98.3	99.3	99.4	99.7	100
Time sec.	5.4	5.7	6.3	3.8	3.2	3.8

6 Conclusion

Today's biometric systems prioritize safeguarding users' data security and privacy. There is a significant focus on securing biometric patterns to prevent theft during transmission. Biometric technology stands as a pivotal force steering the world toward a safer and more favorable state. This technology amplifies security measures, enhances speed and convenience, cuts down costs, fosters confidence in electronic commerce, builds trust, and brings about numerous other benefits. Recent years have witnessed heightened growth and advancement in biometric technologies due to escalating security concerns, resulting in accelerated progress across all facets of biometric research. This growth is not only related to the increase in security considerations, but it is also affected by considerations related to the privacy of users, in the field of confidential and safe use of personal information of people that are stored in virtual cases or transmitted through the Internet. In this article, the biometric system is described first. Among identification systems, systems that use physiological or behavioral characteristics of people have more reliability and security level, an example of which is fingerprint identification, which is the most common and widely used method of identification due to its simplicity and high accuracy. The proposed approach is to identify people using fingerprint images where take into consideration that in many cases there is an incomplete image of fingerprints, there is a need to extract more knowledge. In our proposed method, the Gabor filter and SIFT algorithm were combined and used to reduce the noise as an image processing tool;

data features with more accuracy were extracted. Also, PCA was used to reduce dimensions and eliminate redundancy. Then SVM and K_NN classifiers were used comparing their results and choosing the best result between them based on the performance in terms of executing time the accuracy. As it can be seen based on the results shown in the figures above, the successful performance of the proposed algorithm, plus the use of the PCA algorithm, had a clear impact on the results in terms of improving accuracy and the execution of run time. Also, it was noticeable that the SVM classification proved its efficiency over the K_NN classification.

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Conflict of interest: Authors state no conflict of interest.

Data availability statement: The most datasets generated and/or analysed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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