An Overview of Registration Based and Registration Free Methods for Cancelable Fingerprint Template

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Abstract

Cancelable biometric techniques are becoming popular as they provide the advantages of privacy and security, not provided by biometric authentication system. It transforms a biometric signal or feature into a new signal or feature by some transformation. These are non invertible transforms to make sure that the original biometric template cannot be recovered from them. Most of the existing methods for generating cancelable fingerprint templates need an absolute registration of the image. Therefore they are not robust to intra user variations. But there also exists methods that do not require registration of the image. This paper provides a comparison between two such methods, one that needs registration and other that does not need registration.

Keywords: Cancelable biometrics, non invertible transformation, registration, registration free.

1. INTRODUCTION

The three fundamental techniques used in authentication systems are:

a. Something you know – refers to passwords and PINs.
b. Something you have – refers to tokens and cards.
c. Something you are – refers to biometrics.

The first two techniques used in traditional authentication systems are very famous but have certain disadvantages such as, passwords and PINs can be guessed or disclosed through accident or can be intentionally shared, like passwords, cards or tokens can be stolen and passwords need to be memorized. Moreover it cannot distinguish between an authentic user and a user that has gained access to password. To cater these problems, biometric authentication systems are used. Biometric technologies have automated the identification of people by one or more of their distinct physical or behavioral characteristics. Instead of depending on things that an individual may have or may know, it depends on the attributes of people. Biometric verification techniques try to match measurements from individuals like fingerprint, hand, eye, face or voice, to measurements that were previously collected. Biometric authentication systems have advantages over traditional authentication schemes. The advantages are, biometric information cannot be obtained by direct covert observation, it is impossible to share and difficult to reproduce, it enhances user's convenience by alleviating the need to memorize long and random passwords and it protects against repudiation by the user. But even with all these advantages biometric techniques have security and privacy problems. Biometrics like voice, fingerprint, signature etc. can be easily recorded and misused without user's consent. PINs and passwords, if compromised, can be reset, but biometrics once compromised is compromised forever. If a biometric is compromised, then all the applications using that biometric are compromised. Cross matching of the stored information can be used to track individuals without their consent.

Cancelable biometric overcomes these disadvantages. Cancelable biometric is an intentional and systematic repeatable distortion of biometric features in order to protect user specific data. In this, the application does not store the original biometric but transforms it using a one way function and stores the transformed version. This method gives privacy and security as it is computationally very difficult to recover the original template from the transformed version. The transformation can be done either in signal domain or in feature domain. In signal domain, the raw biometric signal acquired from sensor is transformed (e.g. images of faces and fingerprint), while in feature domain, the processed biometric signal is transformed (e.g. minutiae of fingerprint).During the enrollment process, the fingerprint template is distorted by a one way transform, using a user specific key. Then, instead of storing the original fingerprint template, its distorted version is stored in the database. During verification, the query fingerprint template is distorted using the same function and then the distorted version is compared with the original, to give a similarity score.

Several approaches have been proposed regarding cancelable biometrics. This paper focuses on comparison between two methods used to generate cancelable fingerprint template. There are many approaches that construct cancelable fingerprint template and need absolute registration of the image before transformation [1], [7], [8], [9], while there also exist approaches where registration is not an absolute requirement and purely local measurements are sufficient for this purpose [3], [15]. Further part of the paper is organized as follows. The requirements for generating cancelable transform are explained, then the registration process which is the most important step in fingerprint matching is explained. Further part presents the registration based method and registration free method for generating cancelable fingerprint template followed by a comparison between the two methods and conclusion.

2. REQUIREMENTS FOR GENERATING CANCELABLE TRANSFORM

There are several challenges to overcome before successfully designing a cancelable transform that transforms the fingerprint template into a cancelable template. They are:

1. If two fingerprint templates x_1 and x_2 do not match, as they do not belong to the same individual, then, even after applying the transformation they should not match.
2. If two fingerprint templates match, as they belong to same person, then they should match even after applying the transformation.
3. Transformed version of the biometric should not match with the original biometric.
4. Two transformed versions of same template should not match.

3. REGISTRATION

One more very important requirement for generating cancelable fingerprint template is 'registration'. But this step is not always required. This depends on which method is used for generating the cancelable fingerprint template. It is required when the method used is registration based and not required when the method is registration free. In this paper, two methods, one registration based and other registration free are studied and are compared to review their characteristics.

Fingerprint registration explained in [6], [12] is a very critical step in fingerprint matching. Although a variety of registration alignment algorithms have been proposed [10], [11], accurate fingerprint registration remains an unsolved problem. Fingerprint registration involves finding the translation and rotation parameters that align two fingerprints. In order to determine the degree of similarity between two fingerprints, it is first necessary to align the prints so that corresponding features may be matched. Aligning two images can be done in a number of ways like extracting the minutiae and then aligning, using orientation field for aligning, aligning based on generalized Hough transform [14], identifying distinctive local orientations and using them as landmarks for alignment, etc. Alignment has to be explored first, for matching the corresponding components of two templates or images. Traditional approach of fingerprint registration is based on aligning minutiae features. Given two fingerprint images all of the minutiae are extracted from each print and their location, orientation and type are recorded. Registration is based on aligning these two minutiae sets. For two sets of minutiae M1 and M2, ideal case of transformation is

$$f(M1) = M2 \tag{1}$$

However, ideal transformation does not exist since it is practically impossible for a user to place exactly the same part of his/her finger on a sensor and exert the same pressure on the sensor during two different fingerprint capture occasions. The error between the transformed version and the original fingerprint template $E(f(M1), M2)$ has to be minimized and for this optimal transformation has to be found out. Matching minutiae sets has following limitations:

1. Every time a fingerprint is obtained, a different area of the finger surface may be captured. Therefore alignment should be based only on the overlap area of the print and the corresponding minutiae subsets.
2. Missing and spurious minutiae are common when the fingerprint image quality is low. Therefore the alignment algorithm must allow some minutiae to be unmatched even in the area of overlap.

It is known that fingerprint deforms when pressed against a flat surface. This deformation changes the locations and orientations of the minutiae making it impossible to find a perfect alignment of the subsets.
Therefore most registration algorithms attempt to find an alignment that minimizes these errors. But finding the optimal alignment is very difficult. Due to large number of possible translations, rotations and distortions, aligning fingerprint has a high computational overhead. One way to deal with these complexities is to use supplementary information from other fingerprint features to help the alignment process. Other features that can be used are local structural features, ridge shape, pixel intensities etc.

4. REGISTRATION BASED GENERATION OF CANCELABLE FINGERPRINT TEMPLATE

Ratha et al [1], [2] pioneered the concept of cancelable biometrics where they have proposed three transformation methods.
In the first method, i.e. the Cartesian coordinate transformation method, the image plane is divided into rectangles and then the rectangles are shuffled based on the user password such that any two rectangles can map to a single rectangle. Figure (1) shows that more than two cells can be mapped to the same cell.

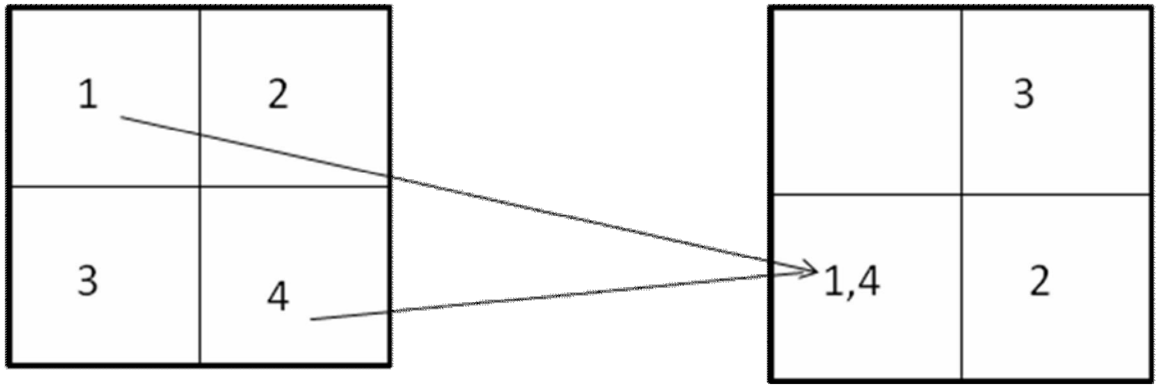


Figure 1: Cartesian Transformation

In the second, i.e., polar transform method, the same technique is applied but now the minutiae positions are measured in polar coordinates. The process of transformation consists of changing the sector position. But in polar coordinates the size of sectors can be different (sectors near the center are smaller than the ones far from the center). Restrictions are placed on the translation vector generated from the key so that the radial distance of the transformed sector is not very different from the original. Figure (2) explains the polar transformation.

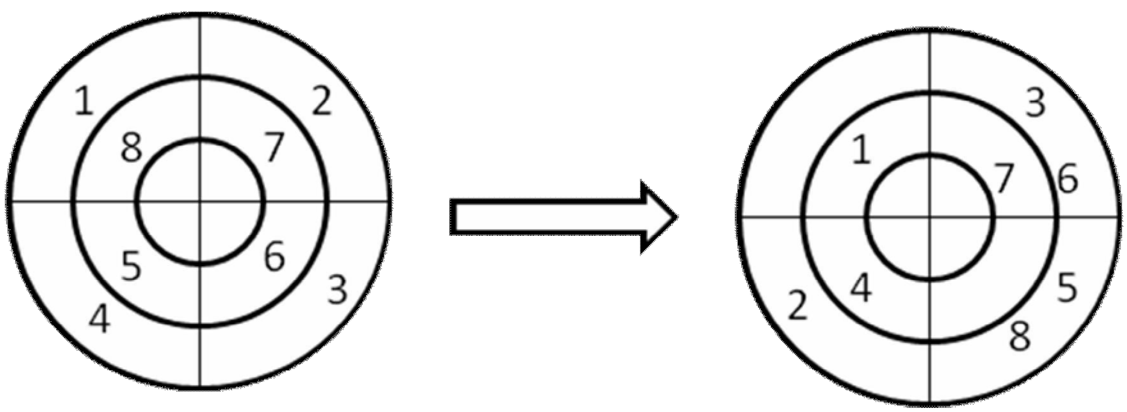


Figure 2: Polar Transformation

As there is 'many to one' mapping, it is impossible to tell which minutiae in the resulting block are from which original cell even if, both transformation and the transformed pattern are known. But the disadvantage with these two methods is that a small change in the minutia position in the original template can lead to a large change in the minutia position after transformation if the point crosses a sharp boundary. This can happen due to intra user variations i.e. variations occurring when the fingerprint of the same person taken at two different instances are different.

In the third method i.e surface folding, a smooth but non invertible functional transform is used to give high performance. Several constrains are put on the non invertible function. They are:

1. The transformation should be locally smooth but not globally smooth.
2. The transformation should be 'many to one' to make sure that it cannot be uniquely inverted to recover the original minutiae pattern.
3. Each minutiae position must be pushed outside the tolerance limit of the matcher after transformation.

In this method the minutiae positions are moved using two dimensional Gaussian functions. Each user is given a unique key which specifies the centers and the shapes of Gaussian kernels. These Gaussian kernels are mixed to generate two functions $F(x,y)$ and $G(x,y)$. They are used to decide the direction and amount of shift for each minutia at (x,y). The direction of translation (phase) is represented as the gradient of the mixture and the extent of translation (magnitude) is represented as the scaled value of the mixture. The Gaussian mixture $F(z)$ is given as

$$\left|\vec{F}(z)\right| = \sum_{i=1}^{K} \frac{\pi_i}{\left|2\pi\Lambda_i\right|} \exp\left\{ -\frac{1}{2}(z-\mu_i)^T \Lambda_i^{-1} (z-\mu_i) \right\} \tag{2}$$

$$\Phi_F(z) = \frac{1}{2}\arg\left\{\nabla\vec{F}\right\} + \Phi_{rand} \tag{3}$$

Where $z = x + iy$ is the position vector K is a random key that defines the parameters of distribution such as the weights π_i, covariances Λ_i, the centers of kernels μ_i and the random phase offset Φ_{rand}. Another function $G(z)$ and its phase $\Phi_G(z)$ are defined in a similar way. Then a transformation $(x, y, \Theta) \rightarrow (X', Y', \Theta')$ is given by

$$X' = x + K\left|\vec{G}(x,y)\right| + K\cos\left(\Phi_F(x,y)\right) \tag{4}$$

$$Y' = y + K\left|\vec{G}(x,y)\right| + K\sin\left(\Phi_F(x,y)\right) \tag{5}$$

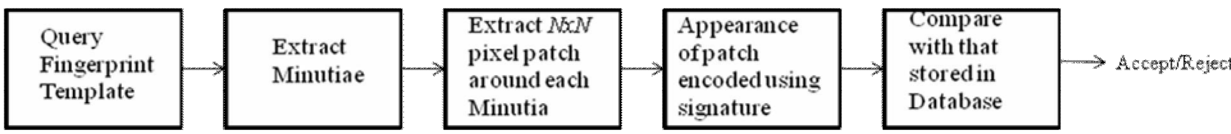
$$\Theta' = \operatorname{mod}\left(\Theta + \Phi_G(x,y) + \Phi_{rand}, 2\pi\right) \tag{6}$$

The Surface folding method is preferred over the other two methods due to their limitation in handling the intra user variation. The Surface folding method performs better than the Cartesian version and is comparable to the polar version.

4. REGISTRATION FREE GENERATION OF CANCELABLE FINGERPRINT TEMPLATE

Ratha et al [3] explained a registration free construction of cancelable fingerprint template. They have presented a new fingerprint representation based on localized, self aligned texture features. Most of the existing methods for generating cancelable fingerprint template need absolute registration process. But finding the optimal alignment is very difficult. Due to large number of possible translations, rotations and distortions, aligning fingerprint have high computational overhead. Although there are methods for getting accurate registration [10], [11], a small error in the process can lead to a faulty cancelable template leading to high 'false reject' during authentication. Also, absence of singular points can lead to failure. In this paper they have shown that absolute registration is not required and that purely local measurements are sufficient for this purpose. The process of enrollment and verification are shown in the figure (3).

(a)



(b)

Figure 3: (a) Enrollment Process (b) Verification Process

Enrollment

In the first stage, minutiae are extracted from the template. Then instead of storing the information regarding the minutiae, a $N \times N$ pixel patch around the minutia is extracted. The patch orientation is aligned with that of the minutia. This approach is based on the fact that each patch provides information about the unique identity of the individual. Common patches are non informative but patches with rare appearances have strong association with the identity of the person. The appearance (texture) of each patch is encoded using a compact signature. Each patch and its signature are stored in the database along with the identity of the person associated with the fingerprint.

Verification

During the verification process, minutiae are extracted from the query fingerprint. The $N \times N$ pixel patch around each minutia is encoded to generate a signature similar to the enrollment process. Then the set of signatures generated from the query fingerprint are compared with that stored in the database. The fact, that the distances are preserved under cancelable transformation, is used in this approach. Given two sets of minutiae signatures $\{x_1, x_2, ...\}$ and $\{y_1, y_2, ...\}$ and the distance between each match $D(x_i, y_j)$, the optimal minutiae correspondence is obtained by minimizing $\sum_i D(x_i, y_{T(i)})$, where $T(i)$ represents the index of the minutia in set $\{y_i\}$ that corresponds to x_i in the set $\{x_i\}$. Once the minutiae correspondence is established, the similarity measures across all matching minutiae signatures are aggregated to either accept or reject the query fingerprint.

Implementation Details

The implementation is done by representing the aligned patch compactly using a Gabor basis expansion. Similarity metric is derived from the normalized dot product distance metric d (). Some of the similarity measures described are: simple count, log weighting and inverse weighting. During verification, the reference set of signatures is compared with the query set of signatures. The evidences from each matching pair are combined to generate the similarity measure for the fingerprint as a whole. The transform is made cancelable with the help of user specific projection matrix (B_k)

$$T(x,k) = B_k{}^T x \tag{7}$$

The distances will be preserved if $B_k B_k{}^T = I$. For this, the matrix B_k has to be orthogonal matrix, which can be synthesized from a random matrix by some orthogonal matrix decomposition method. The linear transformation $B_k{}^T x$ is invertible transformation. To make it non invertible, non-linearities are introduced in the transformation. A discretized projection is used as the patch signature, but this reduces the individuality of the transformed signature. Another technique, two factor key, where the transformation matrix B_k is split into two components can also be used to make the transform non invertible. This splitting can be achieved by SVD decomposition on a random matrix.

5. Discussion

In [3] the set of signatures generated from the query fingerprint are compared with that stored in the database. This comparison has two technical challenges: 1) How to measure similarity between signatures and 2) How to establish minutiae correspondence. As registration of image is done prior to transformation, the problem of minutiae correspondence does not occur in [1]. However, perfect registration itself is a big challenge.

In [1], all the three methods of transformation need absolute registration. Fingerprint registration as described earlier is a critical step in fingerprint matching. Accurate fingerprint registration is very difficult to achieve. Aligning two sets of minutiae needs a perfect transformation function. Achieving ideal transformation is almost impossible due to intra user variations. Although algorithms exist for accurate registration, any error in the process can lead to a ‘false reject’ during authentication. Absence of singular points can also lead to failure. Due to these limitations for getting accurate registration, in [3], [15] registration free method for generation of cancelable fingerprint templates is described. The method for generating cancelable template is free of any registration process as it is based on the information of neighboring local regions around minutiae.

In [1], in surface folding technique, although the process of aligning has high computational overhead, numbers of calculations during actual transformation are less compared to the calculations required in the patch based technique [3]. In patch based technique, two sets of minutiae ‘signatures’ being available, the distance measure from each match has to be calculated to find the optimal minutiae correspondence. The folding technique is a more compact representation making it suitable for memory limited applications.

In [1], in surface folding method, the transformation used is non invertible. But in [3] the patch based method, the proposed transformation is invertible. To make it non- invertible, non- linearities are added to the transformation.

In [1], the surface folding method is preferred over the other two. It performs noticeably better than Cartesian version and is comparable to the polar version. In [3], the localized patch based representation does not require registration and also provides a viable verification scheme. The patch based method is developed further to make the representation cancelable and it is also shown that it is resilient to adversarial attacks.

6. CONCLUSION

Two techniques for generating cancelable fingerprint templates are compared. The patch based technique is registration free while the surface folding technique needs absolute registration, so for fingerprints without singular points, it will fail. The surface folding technique has a non invertible transform while the patch based technique has to be made non invertible as the transform used is invertible. The surface folding technique is a compact way of representation and is suitable for memory limited applications.
Cancelable biometric provides a solution to address the privacy and security concerns about biometric authentication as it is computationally very difficult to recover the original template from the transformed version.

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