A Performance Improvement Method for Existing Fingerprint Systems

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Abstract. How to improve the performance of an existing fingerprint system is an interesting and meaningful problem. Considering the widespread deployment of fingerprint systems, the performance improvement method is very practical and instructive to not only the existing fingerprint systems but also the next biometric systems. In this paper, we propose a novel performance improvement method based on fingerprint's Möbius representation and Choquet integral for an existing fingerprint system. The basic idea of our method is to map the fingerprint similarity as a distance in a geometric space firstly, and then transform the similarity problem between the impressions into a geometric problem through using multiple impressions, and last, map the results obtained in geometric space back to solve the fingerprint similarity problem. The experiments show that the performance achieved by using this method is better than that of other methods.

Keywords: biometric, non-additive measures, Choquet integral, Bayesian inference, maximum likelihood estimation (MLE).

1 Introduction

Biometric systems are rapidly gaining acceptance as one of the most effective technologies to identify people. A biometric system is essentially a pattern recognition system that acquires raw data from an individual, extracts a notable feature set from the raw data, compares this feature set against the feature sets stored in the database, and executes an action according to the result of the comparison. In biometric community, fingerprint recognition is the most popular technology. With the development of fingerprint recognition technology, many fingerprint recognition systems based on various algorithms have been developed and deployed. Nowadays, there are a lot of fingerprint recognition systems existing in a wide range of applications: from physical access control to criminal

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investigation and from inmates managing to corpse identification. Most of these systems are developed based on a certain out-fashion algorithm. The performance of these systems is usually worse than that of present systems. So how to improve the performance of an existing fingerprint system is an interesting and meaningful problem.

In fingerprint recognition community, most researches work on developing new technologies to improve each stage in recognition, including sensing, feature extraction, matching, classification, indexing and so on. Few work aims at improving the performance of an existing system. Obviously, this kind of method is system level one. When we talk about system level method, we usually considered a multibiometrics technology. Many researchers try to use multibiometrics systems to achieve better performance by consolidating the evidence presented by multiple biometric sources [1]. For example, by combining the fingerprint system and face system or several fingerprint systems using deferent type of algorithm, the performance of system can be enhanced. However, these methods, the way to enhance the performance of system through introducing another biometric system, are very costly in all aspects. On the other hand, many researches have shown that the performance of system based on single fingerprint, single feature or single classifier encounters some drawbacks in some applications, and multimodal fingerprint-based methods, including multiple features, multiple matchers, multiple fingers and multiple impressions of the same finger [2], have received more and more attention.

Considering the widespread deployment of fingerprint systems, the performance improvement method is very practical and instructive to not only the existing fingerprint systems but also the next biometric systems. In this paper, we propose a novel performance improvement method based on fingerprint's Möbius representation and Choquet integral for an existing fingerprint system. The basic idea of our method is to map the fingerprint similarity as a distance in a geometric space firstly, and then transform the similarity problem between the impressions into a geometric problem through using multiple impressions, and last, map the results obtained in geometric space back to solve the fingerprint similarity problem. The experiments show that the performance achieved by using this method is better than that of other methods. This idea was briefly introduced in an earlier work [3]. In this paper, the whole approach we improved is described, and the results of systematic experiments are reported.

2 System Analysis and Related Work

2.1 System Analysis

A typical fingerprint verification system involves two stages: during enrollment, the user's fingerprint is acquired and its distinctive features are extracted and stored as a template; and during verification, a new fingerprint is acquired and compared to the stored template to verify the user's claimed identity. Suppose there is an existing fingerprint system. That means there are a database, an enrollment module and a verification module we can utilize. Using the enrollment module, an impression can be extracted as a feature set named template. Using the verification module, we can compute the similarity between two impressions or templates.

In enrollment stage, the fingerprint system usually needs to acquire several impressions of the same finger for checking eligibility of the finger. However, in verification stage, not all the impressions are utilized for comparison. Traditionally, only one typical impression or template stored in the database is selected as user's standard template. Other impressions or templates will never be used after eligibility checking stage. When a query image is imputed, the system compares the query image and standard template using verification module, then determines the result whether the query is the claim itself through considering the similarity.

Clearly, the multiple impressions are utilized insufficiently in traditional fingerprint systems excepting eligibility checking. We address that the performance of the system can be enhanced if the relationships among all enrolled impressions and query image were fully utilized.

2.2 Similarity

In the previous work [3], we propose that the matching score, as a similarity measure of two impressions, can be transformed to a distance in geometry. A better performance of fingerprint system can be achieved through transforming the similarity problem between the impressions into a geometric problem by using multiple impressions. More details can be found in [3].

2.3 Möbius Representation of Impression

We propose that the impression can be represented by Möbius transform. The Möbius representation is defined as follow:

Definition 1. Any set function ν*: P(N)→R* can be uniquely expressed in terms of its Möbius representation [4] by

$$\nu(T) = \sum_{S \subseteq T} m_\nu(S), \forall T \subseteq N \tag{1}$$

where the set function m_ν*:P(N)→R* is called the Möbius transform or Möbius representation of ν and is given by

$$m_\nu(S) = \sum_{T \subseteq S} (-1)^{s-t} \nu(T), \forall S \subseteq N \tag{2}$$

Using the Möbius representation, we can treat fingerprint impressions from a novel perspective. An impression can be regarded as a combination of several regions. Each region contains the overlap with other impressions respectively. Therefore, the importance of each region for recognition performance is vary. Through the introduction of importance parameters, we can describe in detail the effect of each region for recognition to gain a better expression of fingerprint. Naturally, we will introduce the non-additive measure to get the job done.

2.4 Choquet Integral Based Similarity Measure

Within the fields of economics, finance, computer science and decision theory there is an increasing interest in the problem how to replace the additivity property of probability measures by that of monotonicity or, more generally, a non-additive measure. Several types of integrals with respect to non-additive measures, also known as fuzzy measures, were developed for different purposes in various works. The Choquet integral, as a popular representation of the non-additive measure, has been successfully used for many applications such as information fusion, multiple regressions, classification, multicriteria decision making, image and pattern recognition, and data modeling.

Using Choquet integral, we can link the Möbius representation of fingerprints and recognition performance. Typically, we can calculate the utility parameters through regression algorithms. Thus, a fingerprint recognition problem can be converted to a distance computation problem in geometry space by using the Choquet integral based similarity measure.

3 Our Method

3.1 Overview

Let Q be a query image and t be the tth impression used as template. The existing fingerprint system can be regarded as determining the result whether the query is the claim itself depended on $S(Q, I^t)$. A key different between original and improved system is that there is an additional module used to build a model for query image and multiple impressions, as illustrated by Fig. 1 and Fig. 2. An input of the module is similarity set M, where M is defined as

$$M = \left\{ S(I^i, I^j) | I^i, I^j \in Q \cup F \right\}$$

In this work, we propose a novel model based on Choquet integral to acquire a better recognition result.

As described above, our method is a performance improvement method based on the Möbius representation of fingerprints and the Choquet integral. In the initialization stage of the fingerprint system, the utility parameters are estimated by regression algorithms. In the identification stage, we calculated the Möbius representation for each impression firstly. Then, we calculate and output the Choquet integral of the input fingerprint image as result.

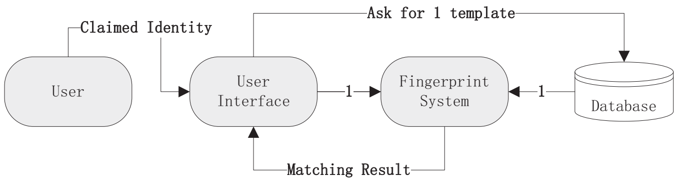

Fig. 1. A framework of an existing fingerprint system

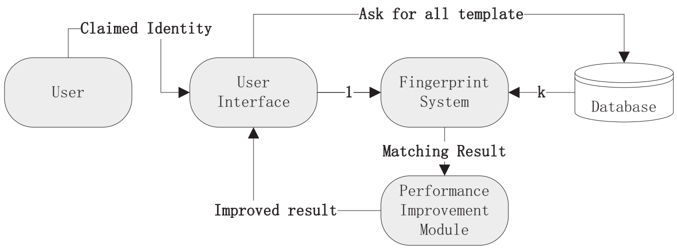

Fig. 2. A framework of the performance improvement method

3.2 Performance Improvement Method

Our method is divided into four parts. The first part is to estimate the position of the fingerprint, the second part is to calculate the Möbius representation of fingerprint impression, the third part is to estimate the utility parameters using regression algorithms, and the fourth part is to calculate the Choquet integral of the fingerprint. These four parts are described in detail as follows.

Estimation of the Position. As mentioned in 2.2, suppose the fingerprint is represented as a circle of radius r, and all distances between any pair of centers of the circle are known. We develop a model to estimate a reasonable two-dimensional position for center of the circle as illustrated in Fig. 3. In this paper, our model is established by Alg. 1.

The Möbius Representation of Fingerprint Impressions. In this work, we use the percentage of each region as the Möbius representation of fingerprint impression. We use Monte Carlo (MC) algorithm to establish the estimation of each region's size. Monte Carlo algorithm is relatively simple and easy to implement [5]. In this paper, we use the 1000 samples for each model.

Estimation of the Utility Parameters. As mentioned in 2.4, given the observation data, the optimal regression coefficients μ can be determined by using regression methods. In this work, we use a maximum likelihood estimation (MLE) [6] method to estimate μ. The MLE method is:

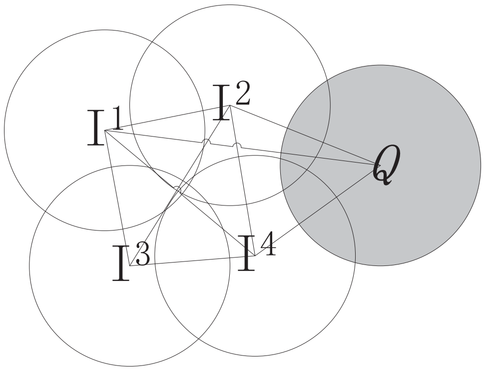

Fig. 3. An illustration of estimation for two-dimensional position. There are four fingerprint impressions in F, Q is the query image.

Alg. 1. Estimation of the Two-dimensional Position

Input: similarity set M
Output: the coordinates of $I^i \in Q \cup F$

- Convert all the similarity measure $S(I^i, I^j)$ to distance $D(I^i, I^j)$
- Find the biggest $D(I^m, I^n)$ among all $D(I^i, I^j | I^i, I^j \in F)$
- Set the coordinate of m as (0,0) and n as $(D(I^m, I^n), 0)$
- For all $I^i \in F$ and $i \neq m, n$
  1. Find $D(I^i, I^m)$ and $D(I^i, I^n)$
  2. Compute the possible position of I^i using a triangle relationship of m, n and I^i
  3. Decide the most reasonable side of I^i via other impressions
- Find the most reasonable position of Q using the coordinates of F and all distance $D(I^i, Q)$

$$\mu_{ML} = \left(\Phi^T \Phi\right)^{-1} \Phi^T \mathrm{t} \tag{3}$$

Here Φ is an $N \times M$ matrix whose elements are given by $\Phi_{nj} = \phi_j(f_n)$ [7], so that

$$\Phi = \begin{pmatrix} \phi_0(f_1) & \phi_1(f_1) & \cdots & \phi_{M-1}(f_1) \\ \phi_0(f_2) & \phi_1(f_2) & \cdots & \phi_{M-1}(f_2) \\ \vdots & \vdots & \ddots & \vdots \\ \phi_0(f_N) & \phi_1(f_N) & \cdots & \phi_{M-1}(f_N) \end{pmatrix} \tag{4}$$

The Choquet Integral of the Fingerprint Similarity. Based on the Möbius representation of the fingerprint, a novel perspective, we can use different utility parameters to obtain various Choquet integral of the fingerprint similarity, as mentioned in 2.4. Further, the different utility parameters also imply the different interpretations for fingerprint similarity. For example, the fully equal utility parameters mean that all regions have the same importance to fingerprint identification; and if the utility parameters of impression overlapping regions were assigned to 0, this approach means the idea of focusing all the recognition method on the separate regions of the impressions.

4 Experiments

The fingerprint databases used in our experiments are FVC2000 DB1, DB2 [8] and FVC2002 DB1, DB2 [9]. FVC DB consists of fingerprint impressions obtained from 100 non-habituated, cooperative subjects. Every subject was asked to provide 8 impressions of the same finger. We select 1st to 4th impressions of every subject as templates and 5th to 8th impressions as query image. Therefore, for each fingerprint, there are four training samples and four test samples.

In this work, we use a minutiae-based automatic fingerprint identification system to complete one to one comparison. For each fingerprint, we match the 5th impression to each of 4 impressions in training set, so a total of 400 homologous match; and match the 5th impression to 4 randomly selected heterologous impressions, so a total of 400 heterologous match.

The performance of a fingerprint verification system is mainly described by two values, i.e., false acceptance rate (FAR) and false rejection rate (FRR). FAR and FRR are defined as

$$FAR = P(D_1|\omega_2) \tag{5}$$

and,

$$FRR = P(D_2|\omega_1) \tag{6}$$

where ω_1 and ω_2 represent the classes of true genuine matches and impostor matches, respectively, D_1 and D_2 denote the decisions of genuine matches and impostor matches, respectively. The Equal Error Rate (EER) is computed as the point where $FAR(t) = FRR(t)$, usually we use EER to evaluate the biometric system.

In this work, we used $\frac{1-S(I^i,I^j)}{1+S(I^i,I^j)}$ as the conversion method from the similarity to the distance. The experimental results show that the performance achieved by using our method is better than that of the original fingerprint system. The average EER of this method is observed to be 1.94%, while that of the original fingerprint system is 4.56%, as shown in Table 1.

Table 1. The experimental results (EER) of performance improvement

	2000-DB1	2000-DB2	2002-DB1	2002-DB2	Average
Original	8.5%	3.75%	4.25%	1.75%	4.56%
Our Method	3.75%	1.5%	1.5%	1.0%	1.94%

5 Conclusion

In this paper, we propose a novel performance improvement method based on fingerprint's Möbius representation and Choquet integral for an existing fingerprint system. The basic idea of our method is to map the fingerprint similarity as a distance in a geometric space firstly, and then transform the similarity problem between the impressions into a geometric problem through using multiple impressions, and last, map the results obtained in geometric space back to solve the fingerprint similarity problem. The experiments show that the performance achieved by using this method is better than that of other methods.

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