ISSN: 2321-7782 (Online)
Volume 3, Issue 11, November 2015
International Journal of Advance Research in Computer Science and Management Studies
Research Article / Survey Paper / Case Study
Available online at: www.ijarcsms.com

Rectifying the Elastic Distortion of Fingerprints for Better Recognition

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Abstract: Although automatic fingerprint recognition technologies have rapidly advanced during the last forty years, there still exists several challenging research problems, for example, recognizing low quality fingerprints. Elastic distortion of fingerprints is one of the major causes for false non-match. While this problem affects all fingerprint recognition applications, it is especially dangerous in negative recognition applications, such as watchlist and deduplication applications. In such applications, malicious users may purposely distort their fingerprints to evade identification. In this paper, we proposed novel algorithms to detect and rectify skin distortion based on a single fingerprint image. Distortion detection is viewed as a two-class classification problem, for which the registered ridge orientation map and period map of a fingerprint are used as the feature vector and a SVM classifier is trained to perform the classification task. Distortion rectification (or equivalently distortion field estimation) is viewed as a regression problem, where the input is a distorted fingerprint and the output is the distortion field. To solve this problem, a database (called reference database) of various distorted reference fingerprints and corresponding distortion fields is built in the offlinestage, and then in the online stage, the nearest neighbor of the input fingerprint is found in the reference database and the corresponding distortion field is used to transform the input fingerprint into a normal one.

I. INTRODUCTION

Fingerprint matcher is very sensitive to image quality , where the matching accuracy of the same algorithm varies significantly among different datasets due to variation in image quality. The difference between the accuracies of plain, rolled and latent fingerprint matching is even larger as observed in technology evaluations conducted by the NIST. Imaging sensor imperfections can be considered as a unique fingerprint identifying a specific acquisition device, enabling various important forensic tasks, such as device identification, device linking, recovery of processing history, detection of digital forgeries. The consequence of low quality fingerprints depends on the type of the fingerprint recognition system. A fingerprint recognition system can be classified as either a positive or negative system. In a positive recognition system, such as physical access control systems, the user is supposed to be cooperative and wishes to be identified. In a negative recognition system, such as identifying persons in watchlists and detecting multiple enrollments under different names, the user of interest (e.g., criminals) is supposed to be uncooperative and does not wish to be identified. In a positive recognition system, low quality will lead to false reject of legitimate users and thus bring inconvenience.

The consequence of low quality for a negative recognition system, however, is much more serious, since malicious users may purposely reduce fingerprint quality to prevent fingerprint system from finding the true identity. In fact, law enforcement officials have encountered a number of cases where criminals attempted to avoid identification by damaging or surgically altering their fingerprints. Elastic distortion is introduced due to the inherent flexibility of fingertips, contact-based fingerprint acquisition procedure, and a purposely lateral force or torque, etc. Skin distortion increases the intra-class variations (difference among fingerprints from the same finger) and thus leads to false non-matches due to limited capability of existing fingerprint matchers in recognizing severely distorted fingerprints. In Fig. 1, the left two are normal fingerprints, while the right one contains severe distortion. According to Veri- Finger, the match score between the left two is much higher than the match score between the right two. This huge difference is due to distortion rather than overlapping area. While it is possible to make the matching algorithms tolerate large skin distortion, this will lead to more false matches and slow down matching speed.

Fig. 1 Sample Fingerprints

Hence it is especially important for negative fingerprint recognition systems to detect low quality fingerprints and improve their quality so that the fingerprint system is not compromised by malicious users. Degradation of fingerprint quality can be photometric or geometrical. Photometric degradation can be caused by non-ideal skin conditions, dirty sensor surface, and complex image background (especially in latent fingerprints). Geometrical degradation is mainly caused by skin distortion. Photometric degradation has been widely studied and a number of quality evaluation algorithms and enhancement algorithms have been proposed. On the contrary, geometrical degradation due to skin distortion has not yet received sufficient attention, despite of the importance of this problem. This is the problem this paper attempts to address. Note that, for a negative fingerprint recognition system, its security level is as weak as the weakest point. Thus it is urgent to develop distorted fingerprint (DF) detection and rectification algorithms to fill the hole.

Literature Survey

Understanding the importance of recognizing distorted fingerprints, researchers have proposed a number of methods which can be coarsely classified into the following categories.

1) Distortion Detection Based on Special Hardware: It is desirable to automatically detect distortion during fingerprint acquisition so that severely distorted fingerprints can be rejected. Several researchers have proposed to detect improper force using specially designed hardware. Bolle et al. proposed to detect excessive force and torque exerted by using a force sensor.They showed that controlled fingerprint acquisition leads to improved matching performance. Fujii proposed to detect distortion by detecting deformation of a transparent film attached to the sensor surface. Dorai et al. proposed to detect distortion by analyzing the motion in video of fingerprint.

2) Fingerprint Registration: In order to extract meaningful feature vector, fingerprints have to be registered in a fixed coordinate system. For this task, we propose a multi-reference based fingerprint registration approach. In the following, we describe how the referencefingerprints are prepared in the offline stage, and how to register an input fingerprint in the online stage.

2.1) Reference Fingerprints: We use 500 fingerprints as reference fingerprints which consist of 100 normal fingerprints from FVC2002 DB1_A, 200 pairs of normal and distorted fingerprints from the training set of Tsinghua DF database. Note that there are no common fingerprints between training and testing data. A large number of references are used in order to properly register fingerprints of various pattern types, while distorted fingerprints are also used as references in order that new distorted fingerprints can be properly registered. A reference fingerprint is registered based on its finger center and direction. For fingerprints whose core points can be correctly detected by a Poincare index based algorithm, the upper core point is used as the finger center. For arch fingerprints and those fingerprints whose upper core points are not correctly detected, we manually estimate the center point. Finger direction is defined to be vertical to finger joint and was manually marked for all reference fingerprints. Since the reference fingerprints were registered in the offline stage, manual intervention is acceptable.

Whorl fingerprint *Arc fingerprint*

Fig.2 Reference Fingerprints

2.2) Online Fingerprint Registration: In the online stage, given an input fingerprint, we perform the registration w.r.t. registered reference fingerprints. Level 1 features (orientation map, singular points, period map) are extracted using traditional algorithms. According to whether the upper core point is detected or not, the registration approach can be classified into two cases.

II. IMPLEMENTATION

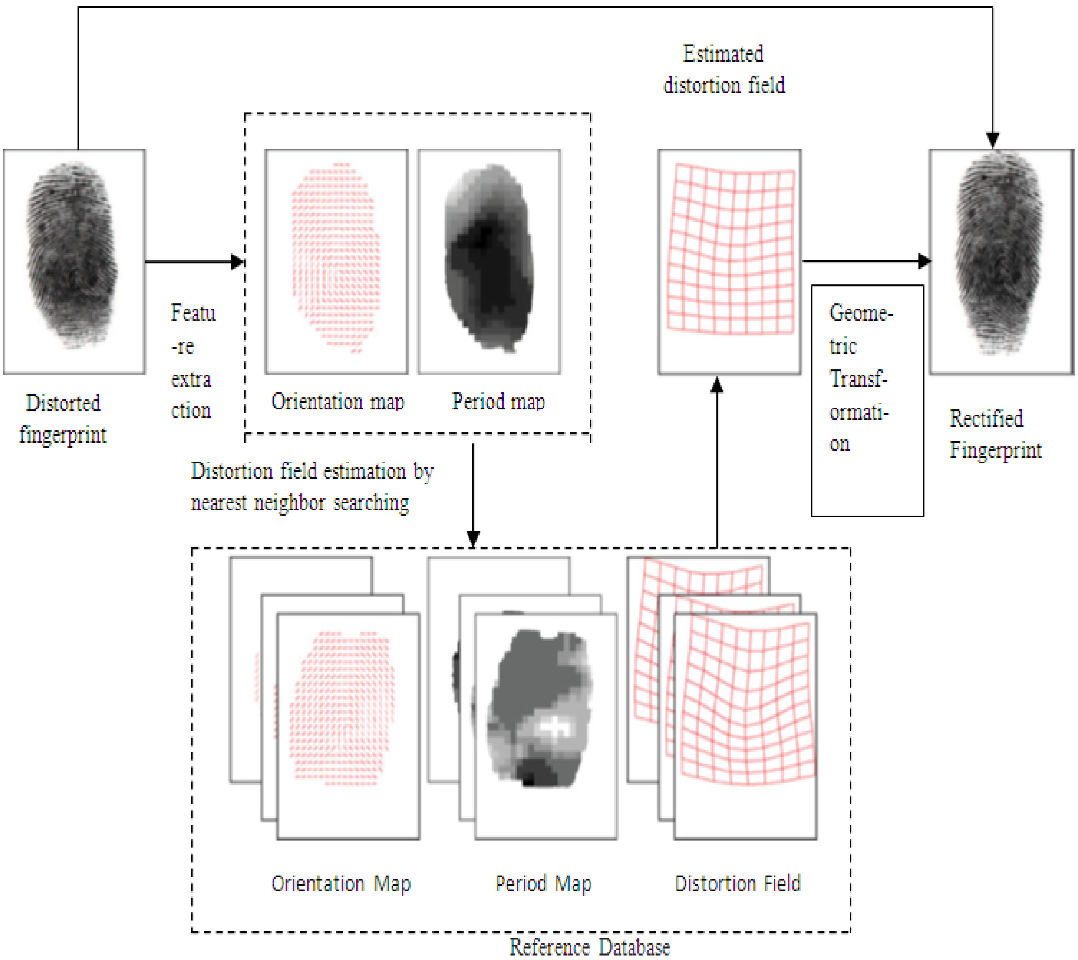

Fig. 3 Rectifying Distorted Fingerprints

A distorted fingerprint can be thought of being generated by applying an unknown distortion field d to the normal fingerprint, which is also unknown. If we can estimate the distortion field d from the given distorted fingerprint, we can easily rectify it into the normal fingerprint by applying the inverse of d. So we need to address a regression problem, which is quite difficult because of the high dimensionality of the distortion field (even if we use a block-wise distortion field). In this paper, a nearest neighbor regression approach is used for this task. The proposed distorted fingerprint rectification algorithm consists of an offline stage and an online stage. In the offline stage, a database of distorted reference fingerprints is generated by transforming several normal reference fingerprints with various distortion fields sampled from the statistical model of distortion fields. In the online stage, given a distorted input fingerprint, we retrieve its nearest neighbor in the distorted reference fingerprint database and then use the inverse of the corresponding distortion field to rectify the distorted input fingerprint.

1) Generation of Distorted Reference Fingerprint Database: To generate the database of distorted reference fingerprints, we use nref ¼ 100 normal fingerprints from FVC2002 DB1_A . The distortion fields are generated by uniformly sampling the subspace spanned by the first two principle components. For each basis, 11 points are uniformly sampled in the interval [2,2]. for an example of generating distortion fields and applying such distortion fields to a reference fingerprint to generate corresponding distorted fingerprints. For visualization purpose, only one reference fingerprint (the fingerprint located at the origin of the coordinate system) is used to generate the database of distorted reference fingerprints, and for each basis, five points are sampled. In practice, multiple reference fingerprints are used to achieve better performance.

2) Distortion Field Estimation by Nearest Neighbor Search: Distortion field estimation is equal to finding the nearest neighbor among all distorted reference fingerprints. The similarity is measured based on level 1 features of fingerprint, namely ridge orientation map and period map. We conjecture that distortion detection and rectification of human experts also relies on these features instead of minutiae. The similarity computation method is different depending on whether the upper core point can be detected in the input fingerprint. If the upper core point is detected, we translate the input fingerprint by aligning the upper core point to center point. Then we do a full search of u in the interval ½_30; 30 for the maximum similarity.

2.1) Performance of Distortion Detection: We view distortion detection as a two-class classification problem. Distorted fingerprints are viewed as positive samples and normal fingerprints as negative samples. If a distorted fingerprint is classified as a positive sample, a true positive occurs. If a normal fingerprint is classified as a positive sample, a false positive occurs. By changing the decision threshold, we can obtain the receiver operating characteristic (ROC) curve. The test set of Tsinghua DF database contains 120 pairs of distorted and normal fingerprints. FVC2004 DB1 contains 791 normal fingerprints and 89 distorted fingerprints, which are found by visually examining the images. As we can see from this figure, the current algorithm performs much better. Although most fingerprints can be correctly classified, there are some false negatives and false positives. False negatives are mainly because the distortion is slight. Fortunately, we found that this is not a severe problem since fingerprint matchers can successfully match slightly distorted fingerprints. As the query fingerprint contains slight distortion, the proposed detection algorithm fails to detect it as distorted one, but the matching score between the query fingerprint and the galley fingerprint is 305, a very high matching score according to VeriFinger. If this query fingerprint is rectified by the proposed rectification algorithm, the matching score can be further improved to 512. False positives are mainly due to low image quality, small finger area, or non-frontal pose of finger. In such cases, there is no sufficient information for correctly aligning and classifying the fingerprint.

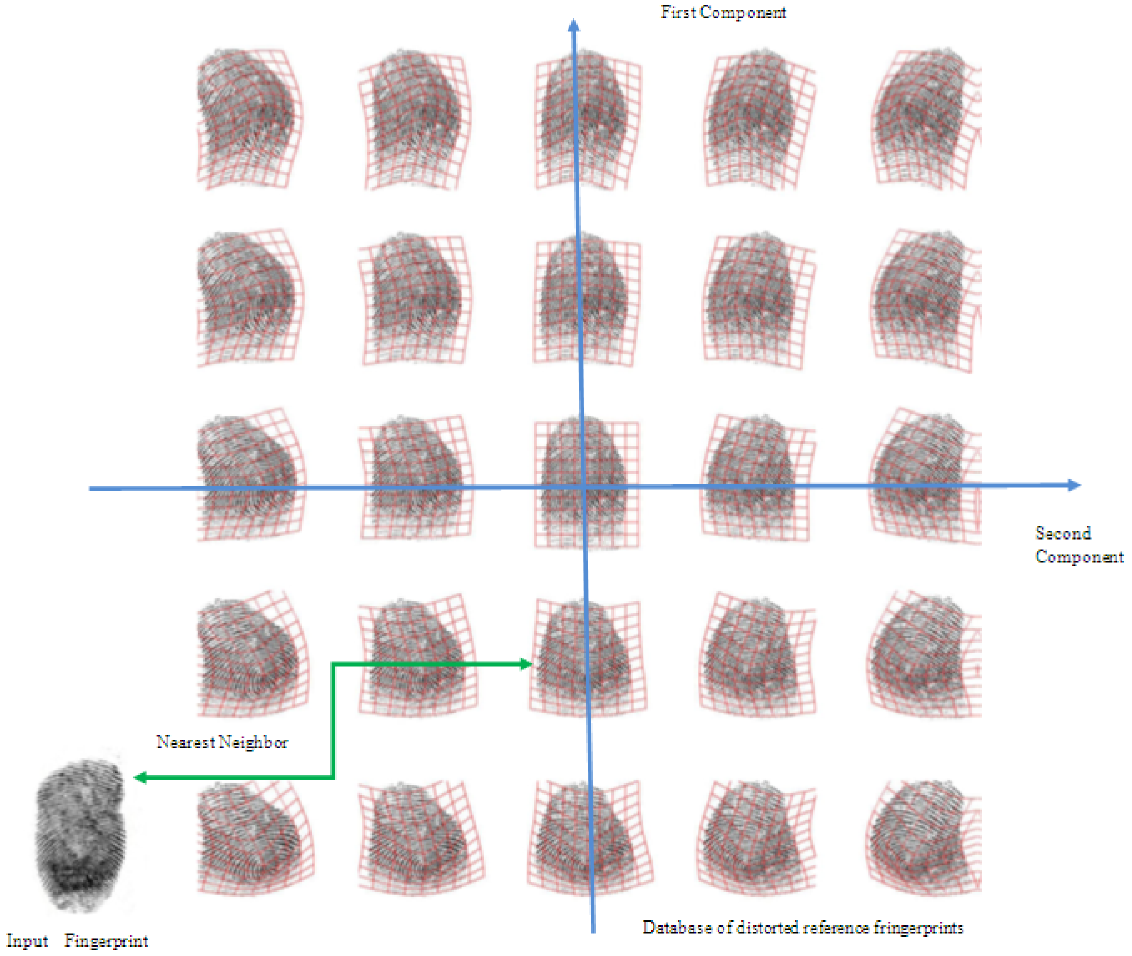

Fig. 4 Matching of fingerprint with the Database

III. Conclusion

False non-match rates of fingerprint matchers are very high in the case of severely distorted fingerprints. This generates a security hole in automatic fingerprint recognition systems which can be utilized by criminals and terrorists. For this reason, it is necessary to develop a fingerprint distortion detection and rectification algorithms to fill the hole. This paper described a novel distorted fingerprint detection and rectification algorithm. For distortion detection, the registered ridge orientation map and period map of a fingerprint are used as the feature vector and a SVM classifier is trained to classify the input fingerprint as distorted or normal. For distortion rectification (or equivalently distortion field estimation), a nearest neighbor regression approach is used to predict the distortion field from the input distorted fingerprint and then the inverse of the distortion field is used to transform the distorted fingerprint into a normal one. The experimental results on FVC2004 DB1, Tsinghua DF database, and NIST SD27 database showed that the proposed algorithm can improve recognition rate of distorted fingerprints evidently.

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