Pattern Recognition Letters 68 (2015) 361–367

Contents lists available at ScienceDirect

Pattern Recognition Letters

journal homepage: www.elsevier.com/locate/patrec

Recovering and matching minutiae patterns from finger knuckle images☆

Ajay Kumar*, Bichai Wang

Department of Computing, The Hong Kong Polytechnic University, Hung Hum, Hong Kong

ARTICLE INFO

Article history:
Available online 26 September 2015

Keywords:
Finger knuckle matching
Image forensics
Emerging biometric modalities
Human identification

ABSTRACT

Personal identification approaches using finger knuckle patterns are receiving increasing attention in the biometrics literature. Several approaches have been explored and these methods consider knuckle patterns as textured-like patterns, similar to the iris, and illustrate promising results. However much of the law-enforcement and forensic analysis for hand biometrics still relies on recovery and matching of minutiae patterns which has matured in last several decades. This is largely due to the fact that the identification of minutiae patterns is believed to be more scientific and pervasive in connecting with the anatomy/uniqueness of individuals. Availability of high resolution finger dorsal images acquired for recreational or covert imaging can provide important cues for forensic investigation and analysis, especially when finger dorsal patterns are only the piece of evidence available for the identification. Identification of finger knuckle patterns using minutiae recovery and matching is expected to significantly help in prosecution of such suspects. This paper therefore investigates recovery and matching of minutiae patterns using finger knuckle images. We investigate effective use of minutiae quality in improving performance for the knuckle pattern matching. Our study detailed in this paper also presents comparative evaluation of performance using three popular minutiae matching approaches. The experimental results presented in this paper from a database from 120 different subjects are highly encouraging and validate such first attempt to study minutiae recovery and matching from finger knuckle images.

1. Introduction

Automated identification of humans using their unique anatomical characteristics has been increasingly investigated for their applications in human surveillance and image forensics. Human fingers are visualized as a complex 3D textured surface consisting of ridges patterns, wrinkles and lines which have been anatomically related to the uniqueness of respective individuals. Finger dorsal patterns are more easily visible from the individuals hand while they are engaged in a variety of day-to-day activities like writing or signing with a pen, driving a car, playing variety of sports, holding smartphones to firearms. Therefore biometric identification using such finger dorsal imaging has great potential in forensics and surveillance while this biometric has not yet been fully explored. The skin surface on finger dorsal surface joining proximal phalanx and middle phalanx bones is referred to as finger knuckle biometric and is believed to be quite distinctive among individuals. Finger dorsal/knuckle images can also be simultaneously acquired using a low-cost camera while imaging fingerprints, finger-vein, or palmprints and can significantly contribute to the deployment of a more secure and/or convenient multibiometrics system.

Recent report [1] from National Research Council calls for the design and development of forensic science approaches which are more scientific. Law enforcement and forensic experts highly prefer identification of suspects using scientific techniques that are based on quantitative measurements, representative database and statistical models [3]. Such techniques are easy to replicate, more transparent and can be more easily subjected to the validity and reliability evaluations. This is the key reason for preference and successful use of minutiae recovery and matching techniques for the prosecution of suspects using match from their fingerprint images. Finger dorsal images reveal knuckle patterns that are increasingly explored and employed for the identification of suspects [7]. However, to the best of our knowledge, there has not been any study to explore finger knuckle identification using recovery and matching of minutiae patterns. This paper therefore presents a detailed study on completely automated recovery and matching of minutiae patterns using finger knuckle patterns.

1.1. Motivation and related work

Finger dorsal images have been increasingly investigated for their use in personal identification and image forensics. There are earlier

☆ This paper has been recommended for acceptance by “Paulo Lobato Correia”.

* Corresponding author. Tel.: +852 2766 7254
E-mail address: csajaykr@comp.polyu.edu.hk (A. Kumar).

http://dx.doi.org/10.1016/j.patrec.2015.08.013
0167-8655/

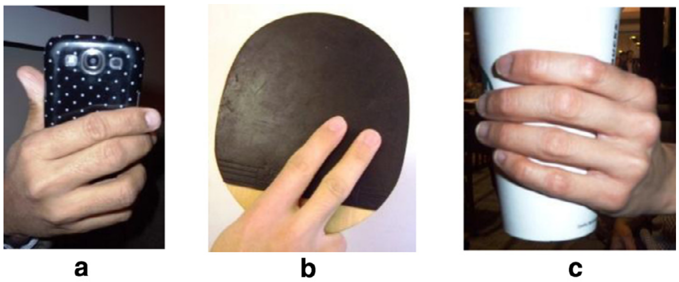

Fig. 1. Samples depicting knuckle patterns from the images available during day-to-day activities like (a) using smartphones, (b) during sports or (c) functions.

references in [17] and [2] that demonstrated the promising use of 2D and 3D dorsal patterns respectively for the automated personal identification. Several references explored the effectiveness of such major knuckle texture patterns using texture analysis methods which have shown their effectiveness for well-established biometric modalities like iris, palm or face. Palm dorsal images provide hand geometry details which can be simultaneously acquired and employed [8] to improve the accuracy of knuckle patterns. The experimental results illustrated in the literature from finger dorsal images acquired using constrained imaging [17–18], contactless imaging [19] and contactless imaging using mobile phone [20] provide strong motivation for further research in using knuckle patterns as a biometric. Finger dorsal images also illustrate minor knuckle patterns that can be employed [22] for personal identification and also used to improve the accuracy of performance that can be obtained from the simultaneously extracted major knuckle patterns. Ref. [16] provides study on stability on knuckle patterns and presents images from over 6 year interval to argue stability of such patterns in various age groups.

Almost all the fingerprint systems employed for the law-enforcement utilize recovery and matching of matching points in fingerprint images. Minutiae based techniques are considered to be more reliable, linked to anatomy of individuals, and successfully employed for suspect identification during courtroom arguments. The finger knuckle patterns typically illustrate curved lines of varying thickness which (unlike fingerprint ridges) are easily visible from the naked eyes at some distance. These curved lines do intersect with similar curves or lines having varying thickness and generate singularities. The singularities in finger knuckle patterns are quite similar to those observed in fingerprints and their relative location can be used to generate feature templates similar to those employed in fingerprints. There has not been any effort to recover and match minutiae patterns from knuckle images. In view of popularity of minutiae based matching for the fingerprints, success of minutiae based matching of finger knuckle patterns can also provide scientific basis for legal arguments in courtrooms and is investigated in this paper.

The contributions from this paper can be summarized as follows. First this paper investigates systematic approach to automatically recover and match minutiae patterns for the personal identification. Second, we also investigate quantification of knuckle minutiae quality recovered from the finger knuckle images and its successful use in more accurately matching the knuckle minutiae. Finally, this paper provides comparative evaluation of three popular minutiae matching approaches, *i.e.*, minutiae cylinder code [9], minutiae triangulation [23] and spectral minutiae matching [13–14], for matching of finger knuckle patterns. Our experimental results are presented on finger dorsal image database of 120 subjects and illustrate promises (average rank-one recognition accuracy of 98% to recognize 120 different subjects) from minutiae matching using knuckle patterns. We also provide a tool [24] to analyze minutiae recovery and matching that can be useful, especially for the forensic scientists to recover and analyze minutiae patterns while matching two knuckle patterns. This study detailed in this paper also identifies the need for further research and development of advanced algorithms to more accurately recover/match minutiae patterns from the finger knuckle images. Fig. 1.

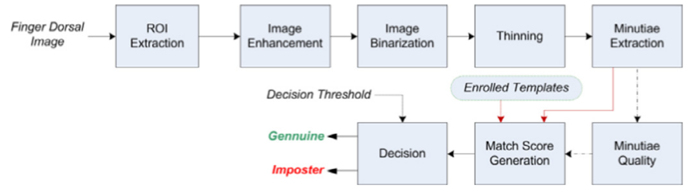

Fig. 2. The block diagram illustrating key steps for automatically recovering and matching knuckle minutiae patterns from finger knuckle images.

2. Image segmentation and normalization

The block diagram of knuckle minutiae based finger knuckle matching approach investigated in this work is shown in Fig. 2. Each of the acquired finger dorsal images is almost in vertical pose and additional orientation alignment is not necessary as the minutiae matching methods are least sensitive to the orientation changes. These images firstly subjected to automated segmentation of region of interest (ROI) images that illustrate major knuckle patterns considered in this work. The ROI segmentation strategy considered in this work is simple and similar as in [8] which can automatically generate normalized and fixed region of interest from finger dorsal images. Each of the images is firstly binarized [11] to generate silhouette representing finger shape (Fig. 3). The length of finger image (L) and length of finger shape (F) in the silhouette is used to extract the knuckle region image of fixed length which is proportional to the length of the finger. This automatically segmented major knuckle image is used for the image normalization as detailed in the following.

Each of the segmented knuckle image is subjected to image enhancement. Unlike prior methods in the literature for the knuckle enhancement whose objective has been to accentuate contrast of textured in local regions, we explored a variety of image enhancement methods that can enhance contrast for curved lines that form major knuckle patterns. Sample results from the usage of median filter, Butterworth filter (first order with cutoff frequency of 1/25), histogram equalization and self-quotient image are shown in Fig. 4. Each of the segmented knuckle image is firstly subjected to Butterworth filter and then used to generate self-quotient image which is used as enhanced image for further processing. The self-quotient image K_q for knuckle image K, is defined as

$$K_q = \frac{K}{\tilde{K}} \tag{1}$$

where $\tilde{K}$ is the filtered image using anisotropic filters as detailed in [10,25]. The self-quotient knuckle image can significantly help to enhance the contrast for major curved lines and also reduce the influence from uneven illumination.

Each of the enhanced knuckle images are firstly binarized [11] and the resulting binarized image is subjected to noise removal using

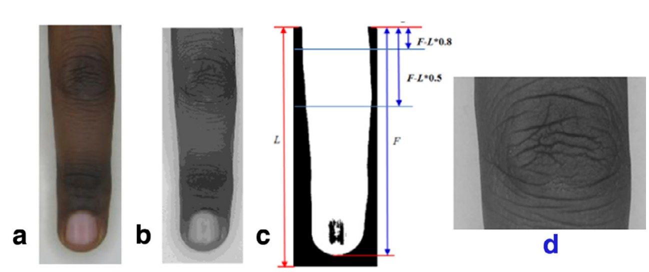

Fig. 3. Extraction of ROI: (a) sample finger dorsal image, corresponding (b) grey level, (c) binarized image and (d) segmented ROI with knuckle patterns.