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A robust singular point detection algorithm

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ABSTRACT

This paper proposes an efficient algorithm to extract the singular points which can be used to classify the given fingerprint. It makes use of a novel algorithm which is a hybrid of orientation field, directional filtering and Poincare Index based algorithms to detect singular points, even when the fingerprint is of low quality or singular point is occluded. Locations of detected singular points are not much accurate and thus they are further refined. Also, some delta points which lie near to the border, may be missed out at the time of detection. Efforts are made to retrieve these missed points. The proposed algorithm also determines the direction of a singular point along with its type (either core or delta). It uses these detected singular points to classify accurately arch, tented arch, left loop, right loop, double loop and whorl type fingerprint patterns. It can handle efficiently the cases of missing delta points during fingerprint classification. The proposed algorithm has been tested on three publicly available databases. It reveals that the proposed algorithm exhibits better singular points detection and fingerprint classification performance in comparison to other well known algorithms.

1. Introduction

A fingerprint (FP) contains patterns of ridges and valleys that flow in a coherent manner. It is one of the most extensively studied and well accepted biometric traits because it satisfies various necessary characteristics of a suitable biometric trait like uniqueness, permanence, difficult to forge, etc. Besides ridge-valley flow, a FP also contains (i) minutiae which are randomly distributed local features; (ii) global features called as 'singular points' (SPs); and (iii) specific type of FP pattern [1]. Any SP can be categorized as either core or delta point which is defined as a concentrate region where the ridge curvature converges to a local maximum or local minimum respectively [2]. This paper proposes an efficient algorithm focused to extract accurately SPs and to detect the FP pattern.

Accurate matching, correct classification, efficient indexing and enhancement are of paramount importance in a FP based biometric system [3]. Most of the times, these are difficult to achieve due to bad quality FPs [4]. Thus, accurate detection of SPs can play a crucial role in solving many problems like (i) indexing large FP database [5], (ii) smoothing OF by reconstruction [6], (iii) synthesizing FPs [7], (iv) alignment of FP which assists in global FP matching [8] and (v) classification of FPs [9]. Thus, reliable extraction of SP is an important problem to be considered.

Extracted SPs are used for FP classification [9–11]. But such SP based classification systems may give erroneous classification results when (i) a SP is left out during acquisition; (ii) a SP is not accurately localized; or (iii) direction of a SP is incorrect. SP can be missed during acquisition when a FP is partially captured due to fixed area of FP acquisition sensor. These are mostly the case with delta points. Thus, unlike existing algorithms, it is better if FP classification can successfully work even in the absence of delta points. Missing of genuine SPs and generation of spurious SPs are the common phenomenon in low quality FP images. Such SPs are inevitably generated [12] due to (i) inappropriate interaction between environment and user which causes partial FP acquisition, (ii) user condition like cuts and bruises on fingertip, (iii) sensor's condition like small area and presence of latent prints, and (iv) occupation or age which can smoothen the ridge-valley structure. Even in good quality FP images, it is observed that SPs can be missed if two core points lie close to each other like in the case of whorl pattern or SPs can be spuriously detected like in the arch type pattern.

Advantages of the proposed algorithm are manifold. The proposed algorithm can accurately detect the SPs even if the FP has low quality or SP is occluded. It reconstructs such areas using a model based algorithm. It detects low false generated minutiae and more genuine minutiae in a time efficient manner. Further, it gives highly accurate location and direction of a SP along with a SP type (core or delta). Moreover, it has proposed a hybrid SP extraction algorithm which recaptures the missed delta points present near

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FP borders. The proposed FP classification algorithm makes use of these extracted SPs for better performance. It reliably detects the arch pattern and even marks a reference point in such pattern. It can correctly distinguish between left/right loop type FPs even in the absence of delta points, which is usually the case when FP is captured in an unconstrained environment. Also, it can accurately distinguish between double loop and whorl pattern which is a challenging task in FP classification. The experiment results conducted on three publicly available databases, reveal that the proposed system exhibit better SP detection and FP classification performance than other well known systems.

The paper is organized as follows. Next section discusses some of the algorithms which are used to design the proposed algorithm. The proposed algorithm has been presented in Section 3, which can be used to extract SPs and to classify FPs. Experimental results are analyzed in Section 4. Conclusions are given in the last section.

2. Preliminaries

This section discusses various algorithms for SP detection and FP classification that are used to design the proposed algorithm.

2.1. SP detection

SP extraction algorithms based on OF can be categorized as (i) Poincare Index (PIindex) based, (ii) directional partitioning based, (iii) template based, (iv) orientation curvature based algorithms, and (v) OF modeling based algorithms.

2.1.1. Poincare Index (PIindex) based algorithm

An algorithm based on PIindex evaluation has the following advantages: (i) it is robust against image rotation, (ii) it gives highly accurate SPs location and (iii) it gives fixed values at each SP location, using which arch type pattern can easily be identified. PIindex value is calculated at each pixel along a closed path (i.e. a block). Let ϑ be such a pixel, surrounded by a block having n_ϑ boundary pixels. Let $(o_1, o_2, \ldots, o_{n_\vartheta})$ be OF of these boundary pixels in a clockwise fashion. Then PIindex value at the central pixel ϑ, $PI(\vartheta)$, is given by

$$PI(\vartheta) = \sum_{i=1}^{n_\vartheta - 1}[f(o_{i+1} - o_i)] + f(o_1 - o_{n_\vartheta}) \tag{1}$$

where f is

$$f(x) = \begin{cases} x, & \text{if } |x| \le \pi/2 \\ \pi - x, & \text{if } x > \pi/2 \\ \pi + x, & \text{if } x < -\pi/2 \end{cases} \tag{2}$$

$PI(\vartheta)$ is equal to $+\pi$ or $-\pi$ at the core or delta point location respectively. Directional image can be used instead of OF for calculating PIindex [13,14].

If PIndex is computed using small block-size, then SPs can be reliably located. But many spurious SPs can also be generated due to noise or bad quality. On the contrary, if larger block-size is used then, true SPs may be missed but it removes spurious SPs. Hence, there is a trade-off between true-miss and false-accept. Other limitations of such algorithms are that (i) these can generate false SP or miss genuine SPs for low quality FP images, (ii) direction of SPs is not estimated and (iii) these are time consuming [15].

Two important properties [16] of PIindex are (i) if a FP image is captured completely then, it should have the same number of core and delta points, and (ii) PIindex value is independent with the integral paths till these paths are homotopic i.e., does not contain any new SP. These properties can be used to remove some limitations of PIindex based algorithms [17,16,18].

2.1.2. Directional partitioning based algorithm

Such algorithms clusters similar orientation, direction [19] or gradient [15]. Such clusters are separated by several boundaries (or *transition lines* [15]). Intersections of these transition lines give the points where the ridge curvatures attain local maxima/minima, i.e. SPs [2]. Estimates of orientation, direction or gradient may be spurious due to the bad quality, hole or minutiae, etc. thus, smoothing operations can be performed which can shift the location of SPs. Another important point to note is that if the number of clusters is increased, then all intersections may not be SPs, but at SP, there must be an intersection. Though these algorithms are computationally efficient, but they may fail to extract SPs when SPs lie close to each other like whorl pattern. Also, this type of algorithms cannot distinguish arch pattern.

2.1.3. Template based algorithms

In template based algorithms [20–22], SP type filters (or templates) are convolved with the FP image to extract singularities. An advantage of such algorithms is that position and spatial orientation of a SP can simultaneously be extracted and this orientation estimate is highly accurate. But such algorithms do not have any defined value for SP. These algorithms use either a threshold or a global maxima to extract SPs. Disadvantage of a threshold based algorithm is that such a threshold which can detect multiple genuine SPs and can avoid spurious SPs, cannot be effectively determined. On the other hand, global maxima based SP detection can detect one core and delta point location. Also, in the absence of clearly defined value of SP, the arch type pattern cannot be determined.

2.1.4. Orientation curvature based algorithms

As areas near SPs have large orientation change, this leads to high curvature [23,24]. Curvature can be measured by various ways [25,26]. Disadvantages of such algorithms are that (i) good number of spurious SPs are generated, (ii) SP can be easily missed due to low quality, (iii) SP type and direction cannot be determined and (iv) it fails to separate arch type pattern as there is no fixed value for SP.

2.1.5. OF modeling based algorithms

If OF used to detect SP is erroneous due to low quality, then it results in a spurious SPs generation or missing of genuine SPs. Therefore, it is smoothed or modeled by using global structure before the detection of SP to remove local noise. Also, missing of genuine SPs is reduced as OFs are accurately interpolated in low quality areas using global constraints. OF modeling algorithms can be divided into two categories based on whether prior knowledge of SPs is required or not. First category which requires prior knowledge of SPs for modeling OF [27–29] and is not of much use in SP detection. Another category which does not require any prior knowledge of SPs for orientation modeling [6,16,30–33] is time-efficient and highly robust against spurious SPs. But OF modeled by it deviates from actual OF, especially near SPs. Thus, the extracted SPs may have poor localization.

2.2. FP classification

FP classification algorithms can be classified as:

1. *Syntactic based algorithms* cluster similar elements [34] and assign a symbol to each cluster. These symbols build grammar for each FP class. For the given FP image, the grammar is obtained and a parsing strategy is used to find the most appropriate FP class. But some FP classes require complex symbol grammar.
2. *Rule-based algorithms* rely on the heuristics and are mainly used with other features (like ridge line shape [35]) for better FP