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# Pixel-level singular point detection from multi-scale Gaussian filtered orientation field

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ABSTRACT

Singular point, as a global feature, plays an important role in fingerprint recognition. Inconsistent detection of singular points apparently gives an affect to fingerprint alignment, classification, and verification accuracy. This paper proposes a novel approach to pixel-level singular point detection from the orientation field obtained by multi-scale Gaussian filters. Initially, a robust pixel-level orientation field is estimated by a multi-scale averaging framework. Then, candidate singular points in pixel-level are extracted from the complex angular gradient plane derived directly from the pixel-level orientation field. The candidate singular points are finally validated via a cascade framework comprised of nested Poincare indices and local feature-based classification. Experimental results over the FVC 2000 DB2 confirm that the proposed method achieves robust and accurate orientation field estimation and consistent pixel-level singular point detection. The experimental results exhibit a low computational cost with better performance. Thus, the proposed method can be employed in real-time fingerprint recognition.



## 1. Introduction

Singular point (SP), as an important global feature of fingerprint, can be utilized to index the fingerprint in large-scale databases, so as to limit the search space [1–6]. It can be used to reconstruct a fingerprint from a template [7], to model the orientation field (OF) [8,9], or to align the enrolled template to the input fingerprint in fingerprint pattern matching [5,10]. Consistent SPs increase the accuracy of fingerprint classification [6] and the performance of fingerprint matching [10].

SP is classified as core and delta and it has two definitions, Henry's definition [11] and OF-based definition. Henry defines the core as the topmost point of the innermost curving ridge, and delta as the center of a triangular region, where three different ridge flows meet. The SPs should be located on the ridge lines. This definition coincides with ISO/IEC 19794-2 [12]. On the other hand, automatic SP detection methods [1,8,9,13–22] define the SPs as the discontinuous points in OF. While both of these definitions can be used in practice, Henry's definition is commonly used in finding a reference point manually in evaluating the performance of SP detection [15,19]. However, the true position of SP is often difficult to determine manually, even by experts. People may comprehend this definition differently in practice.

Fig. 1b compares Henry's definition-based SP (HDSP) with the OF-based SP (OFSP). HDSP is located somewhere within a circle centered at the ideal SP while OFSP obtained by the proposed method is labeled as the black square above the circle. Since, in general, the OFSP is not completely identical with the HDSP in the coordinates of SP due to the smoothing procedures [3,6,23,24], there exists a tradeoff between coordinates excursion and smoothing effects. Furthermore, the important issue in both definitions is the robustness and the consistency of the detected SPs.

Many approaches of SP extraction are found in the literatures and these approaches can be categorized into Poincare index-based and non-Poincare index-based approaches. The Poincare index (PI), introduced by Kawagoe et al. [4], is the classical way to detect and verify SPs. In this method, the summation of the difference in angle in adjacent vectors, which are associated along with a certain contour, will have special values for SPs and normal points. However, the performance of this method severely depends on the OF estimation. Furthermore, due to the homogenous problem in OF estimation, the single PI-based method has limitation in discriminating false SPs from true ones. The non-PI-based approaches utilize various techniques such as orientation curvature [14,15,21,22], template matching [13,19], and others [1,16,17]. Compared with these latter approaches, PI-based approaches are more robust to image rotation.

Since automatic SP detection is defined in OF, the performance (including both detection error rate and consistency regarding position of SP) of SP detection depends on the OF estimation.

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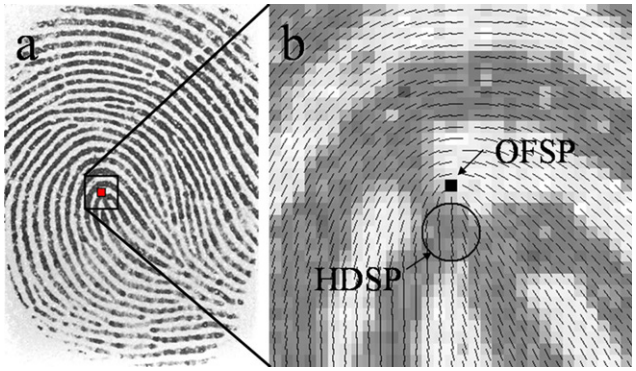


**Fig. 1.** Comparison between Henry's definition-based SP and orientation field-based SP, (a) the original fingerprint image, (b) Singular area superimposed with pixel-wise OF.

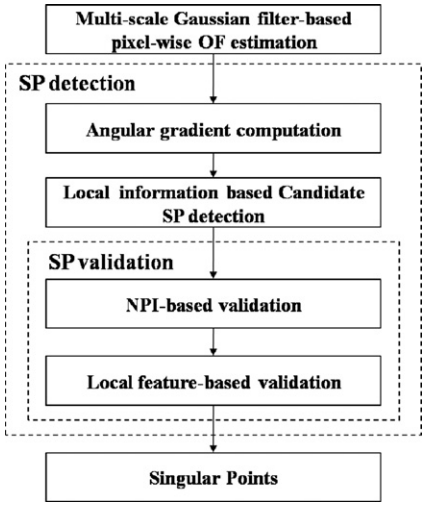


**Fig. 2.** The flowchart of proposed SP detection.

The existing methods of SP detection except the PCA-based approach [18] are based on block-wise OF, thus, the resolution and consistency of SP is limited by the block size in OF estimation since decreasing the block size will introduce much noise. Moreover, the block-wise OF is difficult in finding close SPs, such as two close cores and core-delta pair. The PCA-based method can compute pixel-wise OF using a linear filtering technique, however, the application of single linear filter limits the accuracy of OF estimation, consequently produces many false SPs (refer to Table 2 for comparison).

Motivated by the need to compute consistent pixel-level SPs with a low detection error rate, in this paper, firstly, a robust pixel-wise OF is computed based on multi-scale Gaussian filter. Secondly, the candidate SPs are extracted in the pixel-wise complex angular gradient plane derived from the prior OF. Finally, nested Poincare indices (NPI) and local feature-based classification are used to verify the candidate SPs and to remove the false SPs from the candidate SPs. Fig. 2 shows the flowchart of the proposed SP detection.

Since the OF estimation is based on multi-scale Gaussian filter, the obtained OF has the advantages: (i) robust to local defects, (ii) a pixel-wise OF, thus, pixel-level SPs, (iii) increase in the matching performance [25], and (iv) fewer number of discontinuous points (candidate SPs). Furthermore, the error rate in SP detection is significantly reduced by the cascade framework comprised of NPI in OF domain and local feature-based classification. In addition, in order to remove the subjective evaluation on the performance of SP detection results, a cross correlation matching (CCM)-based method is employed and thus results in objective performance evaluation, whereas the existing methods [15,19] use manually detected SP as the reference point to evaluate the performance of SP detection.

## 2. Pixel-wise orientation field estimation

A reliable pixel-wise OF estimation method is of primary importance in pixel-level SP detection because automatically detected SPs are defined as the discontinuous points in the OF. Robust high resolution OF not only enhances the accuracy in position of SPs but also reduces the number of false SPs. Brief introduction of the pixel-wise OF estimation method was previously published in Ref. [25]. This paper provides more detailed mathematical derivation with an example.

### 2.1. Related works

Several OF estimation approaches have been developed. These approaches can be broadly categorized into four classes: filter-bank-based approach, model-based approach, PCA-based approach, and gradient-based approach. The filter-bank-based approaches [3,6,22,23] estimate the OF based on pixel alignments with respect to a fixed number of orientation masks. Park et al. [2] propose a modified filter-bank which plays a role of a low-pass filter in the frequency domain. The accuracy of the estimated results in the filter-bank-based approach is limited due to the fixed number of reference orientations, block-wise mode, and sensitivity to noise.

Model-based approaches have attempted to model the OF mathematically by taking the global information [8,9,16], quadratic differentials [26], polynomial fitting [27], Markov random field [20], or 2-D Fourier expansion [17]. Model-based approaches are not suitable in finding consistent high resolution SPs because: (i) they need prior-knowledge regarding SP or tradeoff between miss-estimation on good quality areas and the prediction on low quality areas and (ii) the modeled OF has difficulty in representing slight changes in orientation and abrupt changes in SP areas.

Bazen et al. [18] propose a PCA-based approach, which has been proven mathematically equivalent to the conventional squared gradient-based methods, and a modified multi-scale-based approach [28]. Even though this approach produces a pixel-wise OF, it is still sensitive to noise due to insufficient smoothing operation.

The gradient-based approach proposed by Rao et al. [29] has been most widely used in the computation of the dominant orientation of fingerprint images [1,5,14,15,24,30,31]. The orientation of a block in fingerprint is estimated by averaging the squared gradients to avoid directional ambiguity. Several modified gradient-based approaches have been proposed in the literature. Mei et al. [30] estimate the OF in multi-size blocks based on the curvature measure. Wang et al. [31] propose another modified scheme of this conventional squared gradient-based method, where the orientation of a central block is selected by the best orientation from four overlapping neighborhoods that are decided by the coherence measure of each block. The limitations of these gradient-based approaches result from the block-wise mode. It is hard to extract consistent pixel-level SPs from the block-wise OF. Furthermore, due to the presence of noise, corrupted ridge/valley structures, minutiae, etc., the estimated OF is not always accurate. In order to overcome these weaknesses in gradient-based approaches, the multi-scale Gaussian filter-based OF estimation has been proposed in Ref. [25]. This approach is described in more detail in the following sub-section.