A Multi-Scale Approach to Directional Field Estimation

Asker M. Bazen, Niek J. Bouman, and Raymond N.J. Veldhuis
University of Twente - EEMCS - SAS
P.O. box 217, 7500 AE Enschede, The Netherlands
Phone: +31 53 489 3156 Fax: +31 53 489 1060
E-mail: `a.m.bazen@utwente.nl`

Abstract— **This paper proposes a robust method for directional field estimation from fingerprint images that combines estimates at multiple scales. The method is able to provide accurate estimates in scratchy regions, while at the same time maintaining correct estimates around singular points. Compared to other methods, the penalty for detecting false singular points is much smaller, because this does not deteriorate the directional field estimate.**

Keywords— **Biometrics, fingerprint recognition, directional field estimation, multi-scale analysis.**

I. INTRODUCTION

The directional field is a representation of the global shape of a fingerprint, describing the local directions of the ridge lines. It is important in several aspects of fingerprint recognition. It can for instance be used as input for enhancement of the fingerprint, or it can directly be used as a feature vector for recognition. For both applications, an accurate estimate of the directional field is required.

Reported methods for estimating the directional field [1] have the disadvantage that they are sensitive to distortions of the fingerprint image such as, noise and scratches. A solution to this problem is to enhance the directional field by means of low-pass filtering, which can also be interpreted as a reduction of its scale. This solution, however, distorts those areas where relatively large directional field variations are actually present in the fingerprint. As an effect, the directional-field estimates in the areas around the singular points are not reliable, while these are generally considered as the most important areas in a fingerprint.

The method proposed in this contribution does not have these disadvantages. Starting point is a first, possibly noisy estimate of the directional field. This is used as input to a multi-scale method that adapts the filtering to the local curvature of the directional field. The paper describes the method in detail and demonstrates that it is capable of recovering the directional field around scratches while maintaining the locations of core and delta.

This paper is organized as follows. First, Section II gives an in-depth analysis of the problem and describes our new multi-scale approach to directional field estimation. Next, Section III gives some results of the method. Finally, Section IV concludes the paper.

II. MULTI-SCALE DIRECTIONAL FIELD ESTIMATION

A. Problem analysis

Reported methods for estimating the directional field [1] have the disadvantage that they are sensitive to distortions of the fingerprint image such as, noise and scratches. A solution to this problem is to enhance the directional field by means of low-pass filtering, which can also be interpreted as a reduction of its scale. This solution, however, distorts those areas where relatively large directional field variations are actually present in the fingerprint. As an effect, the directional-field estimates in the areas around the singular points are not reliable, while these are generally considered as the most important areas in a fingerprint. As a consequence, it is not even possible to estimate the location of cores and deltas accurately.

Figure 1 shows traditional directional field estimates for a fingerprint that contains a number of heavy scratches. The leftmost figure shows the entire fingerprint, while the middle and rightmost fingers show relevant details. The upper row uses a Gaussian window with $\sigma = 5$ for smoothing. It can be seen that the estimate is accurate in most of the fingerprint, including the region around the core, but it follows the directions of the scratches. Furthermore, it is noisy in low-quality areas (not shown in the figure). The bottom row shows the directional field estimates that are filtered with a Gaussian window with $\sigma = 20$. This estimate does not follow the orientations of scratches, but it is not accurate in the region near the core. More specifically, the core tends to shift upwards when stronger smoothing is applied.

In the model of an ideal core (see [1]), smoothing would not cause displacements of a core. However, a real core differs slightly form the core model. In the area below the core, the ridge lines are in general parallel instead of slightly diverging (except in a some tented arches and pocketed loops). Due to this structure, the parallel ridge orientation that is found below the core is more prominently present in the area around the core. Therefore, this will be the average direction in the smoothed directional

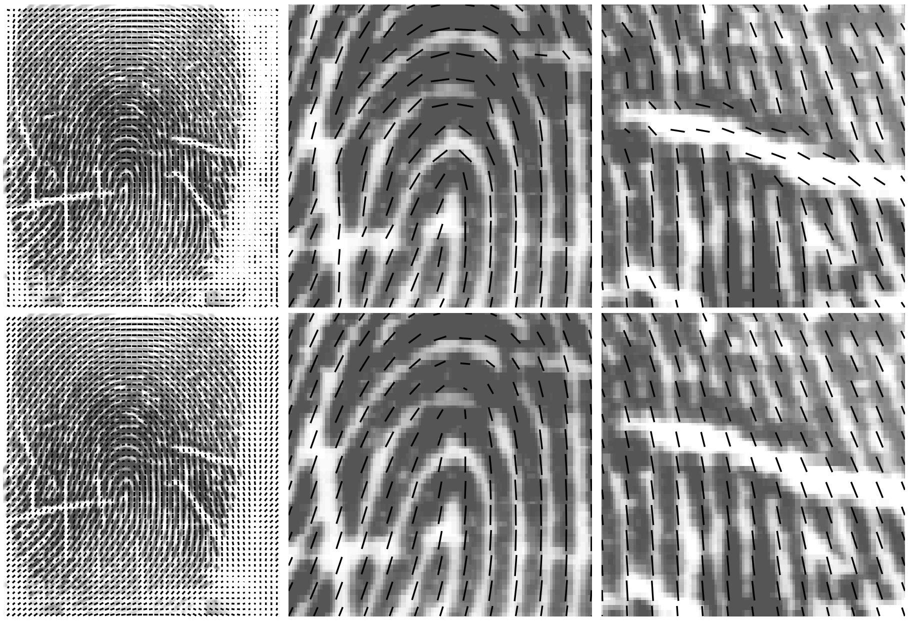

Fig. 1. Directional field estimates for $\sigma = 5$ (top) and $\sigma = 20$ (bottom).

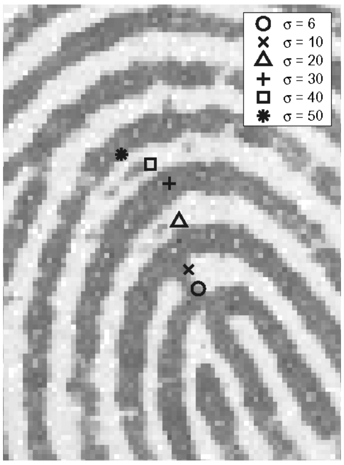

Fig. 2. Trajectory of a core for increasing values of σ.

field, which causes the position of the core to move upward. An example of this upward trajectory is shown in Figure 2 for increasing values of σ.

The method proposed in this contribution does not have these disadvantages. Starting point is a first, possibly noisy estimate of the directional field. This is used as input to a multi-scale method that adapts the filtering to the local curvature of the directional field. The paper describes the method in detail and demonstrates that it is capable of recovering the directional field around scratches while maintaining the locations of core and delta.

B. Alternative methods

As explained in the previous section, smoothing may be able to reconstruct the directional field in scratches, but it does not give an accurate estimate around singular points. Several alternative methods to compensate for scratches in the directional field are known from literature. This section summarizes a few of them, and explains why these methods do not provide satisfactory results.

- Polynomial fit. This method fits a polynomial of relatively low degree to the estimated directional field (see e.g. [2]). It turns out that this method provides the same type of results (positive and negative) as Gaussian smoothing. Additionally, it introduces numerical stability problems into directional field estimation that did not exist without polynomial fitting.
- B-spline model. This method fits a B-spline model, which is a piecewise polynomial model, to the directional field estimate. But again, this provides the same results as Gaussian smoothing.
- Sherlock and Monro model [3]. This method fits a pole-zero model to the directional field. It has two drawbacks. First, the positions of the singular points have to be known in advance, while accurate detection is one of the purposes of finding a robust directional field estimate. Second, it is generally known that this Sherlock and Monro model is not able to provide an accurate approximation to the directional field of a real fingerprint.
- Vizcaya and Gerhardt model [4]. This method fits a non-linear pole-zero model to the directional field. However this model also has some drawbacks. The positions of the singular points have to be known in advance, it still cannot model all directional field that are encountered in practice, and no efficient algorithm to fit the non-linear parameters is known.

- Zhou and Gu model [5]. This method is another improvement upon the Sherlock and Monro model. In this approach, a first model is made by modelling the singular points by a pole-zero model. The model is refined by fitting a low-degree polynomial model to the remaining differences. The main drawback of this method is that the singular points have to be known in advance.
- Gu, Zhou, and Zhang model [2]. This method is another improvement upon the Sherlock and Monro model. It applies a low-degree polynomial model to approximate the global directional field globally. At each singular point, a point-charge (i.e. pole-zero) model is used to describe the local region. Then, these two models are combined smoothly together through a weighting function. The main drawback of this method is again that the singular points have to be known in advance.

A conclusion from this survey is that the known methods for directional field enhancement do suffer from one or both of two problems. First, they do not provide more accurate results than Gaussian smoothing, which means that they do not contribute to solving the problem. Second, the locations of the singular points have to be known in advance. If these are not known accurately, the resulting directional field is completely wrong, while accurate detection of those locations is one of the purposes of a more accurate directional field estimate. Furthermore, these methods may not be able to accurately represent all genuine directional fields.

C. Proposed method

The main reason that a pole-zero model has to be used to approximate directional fields in [2], [5] instead of a smooth polynomial model, is their representation for the directional field, which is a unit-length complex number array. This causes discontinuities around singular points that cannot be modelled by polynomials. By modifying the representation such that the length of the complex numbers is given by the coherence C_g (see [1]), the discontinuities are removed, and modelling has become easier.

Instead of defining a new directional field model, we propose to combine standard directional field estimates at different scales, i.e. using different values of σ for the Gaussian smoothing filter. The questions to be answered are: which scales should be chosen, and how to combine estimates at those scales.

Experiments show that the selected scales are not very critical. Two scales are selected based on the following observations. At scale $\sigma = 5$, the singular points are displaced less than one ridge-valley structure, which is approximately the most accurate estimation that a human expert can make, while most false singular points from lower scales are suppressed. At $\sigma = 20$, the directional field at scratches is reconstructed sufficiently.

One could follow two basic approaches for combining estimates of multiple scales. The first is to use the small-scale model, except where a large-scale model is needed. The second is to use a large-scale model, except where a small-scale model is needed. In the largest part of the fingerprint both models are accurate. Around singular points, a small-scale model is needed, and around scratches, a large-scale model is needed. Since it is much easier to reliably detect singular points than is is to detect scratches, we choose the second approach: use a large-scale model, except at areas around singular points.

We propose two methods to find the singular point regions, where a small-scale model has to be used.

1. The first approach to find the singular point regions is to use a standard singular point detection algorithm (see e.g. [1]) at a range of scales between $\sigma = 5$ and $\sigma = 30$. This method detects the trajectories of the singular points, thus discarding false singular points in the smaller scale estimate. Next, morphology is used to define an area around the trajectories in which the small-scale estimate is selected. In the remainder of the fingerprint, the large-scale estimate is selected.
2. For this specific purpose one could also follow an alternative approach that uses the coherence. The standard coherence C_g measures the consistency of the gray-scale gradients in a local area in the fingerprint image. Additionally, one could also define an alternative coherence measure C_DF ,

$$C_\mathrm{DF} = \frac{|\sum_W \mathrm{SDF}|}{\sum_W |\mathrm{SDF}|} \tag{1}$$

that measures the consistency of the directional field estimate after smoothing in a local area. In this expression, SDF is the representation of the squared directional field by a complex number. Figure 3 shows images of C_g and C_DF with $\sigma = 20$.

The figure shows that C_DF is low where the smoothed directional field is discontinuous, i.e. at the singular point locations. Therefore, C_DF can be used as a basis for combining directional field estimates of different scales. Since C_DF takes only low values at the positions of the singularities in the large-scale estimate, and these positions are displaced from their true locations, small-scale estimates have to be used in a region around low C_DF positions. This is achieved by morphological operations. This approach can also be formulated in other words: where smoothing does not help to remove inconsistencies from the directional field, it is better to use the small-scale estimate instead.

(a) Fingerprint (b) C_g (c) C_{DF}

Fig. 3. Coherence of the gradients (C_g) and coherence of the directional field (C_{DF}) for $\sigma = 20$.

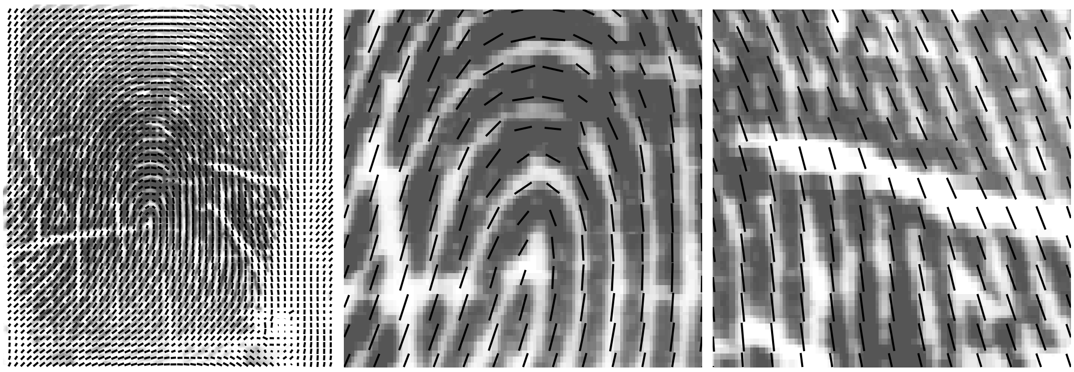

Fig. 4. Directional field estimates for multi-scale approach.

III. RESULTS

The result for selected scales $\sigma = 5$ and $\sigma = 20$ are shown in Figure 4. The figure shows that the combined multi-scale directional field estimate is able to provide accurate estimates in the areas around singular points, while it is also able to discard inaccuracies due to scratches.

Furthermore, detection of a false singular point does not deteriorate the directional field estimate completely, as is the case for methods [2], [5]. Instead, it only gives a local lack of robustness to scratches.

IV. CONCLUSIONS

This paper proposes a robust method for directional field estimation from fingerprint images that combines estimates at multiple scales. The method is able to provide accurate estimates in scratchy regions, while at the same time maintaining correct estimates around singular points. Compared to other methods, the penalty for detecting false singular points is much smaller; this does not deteriorate the directional field estimate.

We realize that the presented evaluation of the proposed method is rather subjective. Therefore, we recommend to perform a complete functional evaluation of the algorithm, i.e. to include the proposed method into a full fingerprint recognition system, and to determine performance of the entire recognition chain with and without using the proposed method.

ACKNOWLEDGEMENT

This research is supported by the Technology Foundation STW, applied science division of NWO and the technology programme of the Ministry of Economic Affairs.

REFERENCES

[1] A.M. Bazen and S.H. Gerez. Systematic methods for the computation of the directional field and singular points of fingerprints. *IEEE Trans. PAMI*, 24(7):905–919, July 2002.

[2] J. Gu, J. Zhou, and D. Zhang. A combination model for orientation field of fingerprints. *Pattern Recognition*, 37:543–553, 2004.

[3] B.G. Sherlock and D.M. Monro. A model for interpreting fingerprint topology. *Pattern Recognition*, 26(7):1047–1055, 1993.

[4] P. Vizcaya and L. Gerhardt. A nonlinear orientation model for global description of fingerprints. *Pattern Recognition*, 29(7):1221–1231, 1996.

[5] J. Zhou and J. Gu. Modeling orientation fields of fingerprints with rational complex functions. *Pattern Recognition*, 37:389–391, 2004.