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Frequency and ridge estimation using structure tensor

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Computing a reliable orientation map is a critical step in automatic fingerprint analysis and especially for analysis of fingerprints obtained at crime-scenes especially. Being the initial step of processing image information it may influence the further operations: registration, enhancement and matching. We suggest a new way of automatic frequency estimation improving the state-of-the-art results [1], [2] favourably for noisy images. We suggest using frequency to steer Structure Tensor [3] which is used to obtain refined orientation maps.

Fingermarks collected from crime scenes are usually low quality images, therefore lacking the support of automatic image analysis methods. Forensic expertise is utilized for the major part of the image analysis: registration of minutia, ridge frequency count, etc. It is desirable to support an expert by providing reliable orientation maps to ease the work. Having orientation maps estimated we can further provide suggestions for an expert (possible minutia location and orientation) to increase his/her efficiency. A structure tensor is a symmetric positive semi-definite matrix that can be utilized for building orientation maps of fingerprints. Response of the gradient filter, upon convolution with the image, is used for estimating frequency of the image. We provide mathematical descriptions to support the method. Suggested method provides maps of frequency that are continuous in the mathematical sense.

We have tested suggested frequency estimation on the NIST SD27 database to perform ridge counting. The fingermark ridge count procedure is desirable but time consuming for an expert as it grows quadratically with the number of minutia we want to count ridges of. Also it is not fully reliable to be done automatically. The ridge count does not only depend on the frequency but also on the wave vector direction connecting two minutia points. We model a fingerprint image in the neighbourhood $R$ around two minutiae with the planar wave $\cos(\omega_0r)$. Here, $\omega_0$ is a known constant wave vector (frequency of the image ridge flow calculated a forehead) and $r$ is the line joining two minutia points.

$$N_L = \frac{L}{T} = \frac{L}{2\pi/(\omega_0|\cos(\varphi_0 - \varphi_L)|)}, \quad (1)$$

where $L$ is the distance between minutiae, $\varphi_0 - \varphi_L$ is the direction of the line joining two minutiae. For infinitesimally small length $L$ and image area $R$ and normalisation function $q (q > 0, \int q = 1)$ we will get the final formula:

$$N_L = \frac{L}{2\pi} \int q(\tau)\omega(\tau)|\cos(\varphi(\tau) - \varphi_L(\tau))|. \quad (2)$$

The quality metrics $q(\tau)$ is introduced to increase the weight of confident ridge count measurements and decrease it for bad quality ridge counts. The metrics is used as well for extrapolation of ridge counts for areas where ridge information is absent.

In order to overcome noise on the forensic dataset we have applied the above-mentioned procedure iteratively. First, we estimated frequency based on the initial image, then we used the obtained frequency for tuning structure tensor. Finally, Gabor filter were used to enhance the image. Initial image is replaced with the enhanced image and the procedure is repeated unless the global average of frequency estimation converges. As a result, we obtain frequency and dense orientation maps providing enhanced image and automatic ridge count.

For the pair of fingerprint images ridge estimation is within 1 ridge for 78% of cases. For some minutiae pairs error in estimation is explained by other minutia on the line connecting the pair. Ridge count for closer minutia reduces this bias and raises the count performance to 83%. Performance of the automatic ridge count algorithm greatly depends on the precision of the minutia placement done by forensic experts (in case of bifurcation it may introduce a false ridge). In 50 randomly selected by human minutiae ridge distances 47 were within 1 ridge with automatic fingerprint ridge count (see fig 1). Remaining 3 cases of falsely estimated number of ridges are made for fingerprints with incipient ridges (see fig. 1) and fingerprint with scar (machine error).

1. References


Figure 1: Examples of the fingerprints having erroneous and correct (minutiae 16-20) ridge count