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Adaptive Fingerprint Enhancement

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Abstract

This project deals with a method of enhancing the degraded detail in the fingerprint images. The term adaptive implies that the parameters of this method are automatically adjusted based on the input fingerprint image. In this method, five processing blocks are involved. The process of fingerprint image enhancement is based on integrating the functionalities of each block. The five blocks are Pre processing, Global analysis, Local analysis, matched filtering and Image segmentation. In the Pre processing and Local analysis blocks, a nonlinear dynamic range adjustment method is used. In the Global analysis and Matched filtering blocks, various forms of order statistic filters are applied. These processing blocks yield an enhanced and new adaptive fingerprint image processing method.

Keywords: *Pre processing, Image Enhancement, Global Analysis, Local Analysis, Matched filtering*

1. Introduction

Among biometrics, fingerprint systems have been one of most widely researched and deployed. Fingerprints are one of the first biometrics to be widely used. It is popular because of their easy access, low price of fingerprint sensors, non-intrusive scanning, and relatively good performance. In recent years, significant performance improvements have been achieved in commercial automatic fingerprint recognition systems. Fingerprint matching is the most popular biometrics technique used in automatic personal identification systems. The first application of fingerprints was in the field of criminal investigation, but nowadays with the progress in computer technology it has become more popular in different fields such as: employee identification, physical access control, and information system security.

2. Image Enhancement

Fingerprint Image enhancement is to make the image clearer for easy further operations. Since the fingerprint images acquired from sensors or other media are not assured with perfect quality, those enhancement methods, for increasing the contrast between ridges and furrows and for connecting the false broken points of ridges due to insufficient amount of ink, are very useful for keep a higher accuracy to fingerprint recognition.

2.1. Image Acquisition

Image acquisition is the first step in the approach. It is very important as the quality of the fingerprint image must be good and free from any noise. A good fingerprint image is desirable for better performance of the fingerprint algorithms. Based on the mode of acquisition, a fingerprint image may be classified as off-line or live-scan. An off-line image is typically obtained by smearing ink on the fingertip and creating an inked impression of the

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fingertip on paper. A live-scan image, on the other hand, is acquired by sensing the tip of the finger directly, using a sensor that is capable of digitizing the fingerprint on contact. Live-scan is done using sensors. There are three basic types of sensors used. They are optical sensors, ultrasonic sensors and capacitance sensors.

2.2. Spatial Domain Enhancement

In a spatial-domain technique, an enhanced image is obtained by convolving the input fingerprint image with a spatial filter mask. The size of the mask dictates the computational complexity of the filtering process. In the spatial-domain, the most popular algorithm for fingerprint enhancement proposed by Hong is based on the directional Gabor filtering kernel. The authors model the gray levels along the ridges and valleys of a fingerprint as a sinusoidal-shaped wave having a direction orthogonal to the ridge orientation. The local ridge frequency is considered as sinusoidal-shaped wave and computed pixel-wise. The filtering kernel proposed in is both frequency-selective and orientation-selective, which makes it to give maximal responses to ridges at a specific orientation and frequency in the fingerprint image.

2.3. Frequency Domain Enhancement

In a frequency-domain technique, an enhanced image is obtained by convolving the input fingerprint image with the frequency domain filter. The convolution in the spatial domain is equivalent to a multiplication operation in the frequency domain. Sherlock have proposed a non-stationary directional filter for enhancing fingerprint images in the frequency domain. A fingerprint image is convolved with pre computed filters located at eight directions with the intervals of 22.5 degrees resulting in a set of filtered images. The enhanced image is reconstructed by a selecting each pixel direction of the filtered images that corresponds most closely to the actual ridge orientation obtained from the original fingerprint image. Finally, a thresholding technique is used to obtain binary enhanced image. The algorithm assumes that the ridge frequency is constant. Therefore, the proposed method does not utilize the full contextual information provided by the fingerprint image. In addition, the algorithm requires computing a large number of pre computed filters to enhance the fingerprint image. Thus, the computational complexity is quite high and thus, not suitable for real-time applications.

2.4. Automatic Enhancement

Existing methods typically keep various parameters, such as local area size, constant. The strategy to keep parameters constant may fail in a real application where fingerprint image or sensor characteristics vary, thus yielding varying image quality. In addition, due to the spatially variable nature of fingerprints, it is crucial to have a sufficient amount of data in each local image area so that the local structure of the fingerprint is enclosed. Hence, the local area size should adapt to the data present. Different fingerprint sensor resolutions provide different normalized spatial frequencies of the same fingerprint and this also requires adaptive parameters. Finger-prints captured with the same sensor may also vary depending on, *e.g.*, gender and age of the user. The negative influence on fingerprint recognition system performance for individuals of different ages was demonstrated in and the matching results. To compensate for varying fingerprint image characteristics and to achieve an optimal system performance, key parameters of most existing methods, *e.g.*, the size of the local area, need to be tuned manually for every fingerprint image. This manual tuning for each image is tedious and costly and automatic systems are therefore desirable.

Normalisation is the next step in the enhancement algorithm. Normalization is done so that the gray level values lies within a given set of values. The fingerprint image is normalized to have a predefined mean and variance. This is required as the image usually has distorted levels of gray values among the ridges and the valleys. Normalization allows standardizing the distorted levels of variation in the gray scale values. Normalization involves pixel-wise operations and does not change the ridge and valley structures.

Normalization is a linear process. Suppose the intensity range of the image is 50 to 180 and the desired range is 0 to 255 the process entails subtracting 50 from each of pixel intensity, making the range 0 to 130. Each pixel intensity is multiplied by 255/130, making the range 0 to 255.

Histogram equalization, as normalization method, is a process to enhance the contrast of images by transforming its intensity values. Usually a fingerprint image has different gray values for every pixel. It is desirable to have the gray value around a mean value. This is achieved by histogram equalization. It increases the local contrast of images. Thus the intensities can be distributed on the histogram. This allows for areas of lower local contrast to gain a higher contrast without affecting the global contrast. Histogram equalization accomplishes this by effectively spreading out the intensity values. The histogram of the original image illustrates that all the intensity values lie on the right hand side of the 0–255 scale, with no pixels in the left hand side. The histogram of the normalized image shows that the range of intensity values has been adjusted such that there is a more balanced distribution between the dark and light pixels. Normalizing the image improves the contrast between the ridges and valleys. It does not alter the shape of the original histogram plot. The relative position of the values along the x axis is shifted.

3. Proposed Method

The proposed method extends an existing adaptive fingerprint enhancement system by incorporating new processing blocks to construct an improved novel system. The proposed fingerprint enhancement method is based on spatial contextual filtering using matched directional filters. A non-linear dynamic range adjustment method is used as a preprocessing stage in this paper. An outlier suppression using a median filter is proposed in the global spectral analysis to further improve the estimation of the fingerprint's fundamental frequency. The median filter suppresses noise and it has also a grouping effect which aids the frequency estimation. The present method furthermore proposes to use local dynamic range adjustment to improve local spectral features estimation, and where order statistical filters are used to smooth the spectral features yielding a robust algorithm behavior.

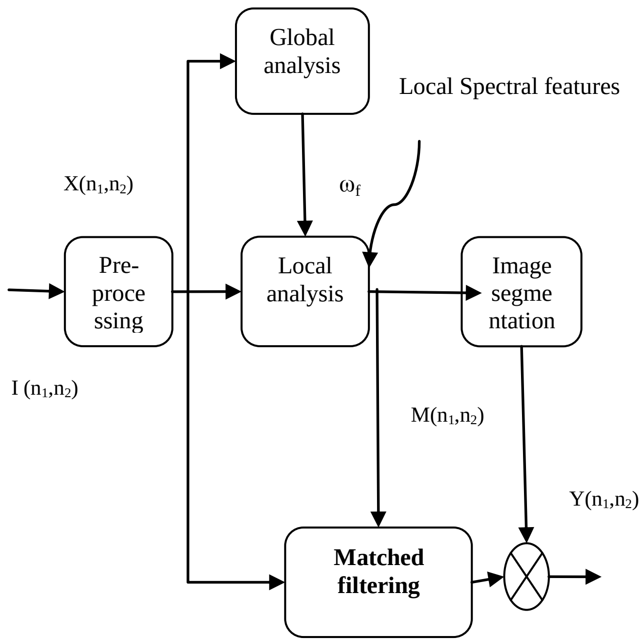

Figure 1. Processing Blocks of the Proposed Method

Local fingerprint image patches are spatially and spectrally similar to a sinusoidal signal, where the dominant peaks in the magnitude spectrums of the two signals are co-located. The location of the dominant peak in the magnitude spectrum of a local image area carries information about the local orientation and frequency of the fingerprint pattern. The magnitude of the dominant spectral peak acts as an indicator of the quality of the fingerprint in that particular local area.

First, an innovative non-linear preprocessing block adjusts the dynamic range of the image. Second, a novel update to the previously derived global fingerprint analysis is conducted to aid the fundamental spatial frequency estimation of the fingerprint image, and where data-outlier suppression further improves the frequency estimation performance for noisy images. Third, based on the estimated fundamental frequency from the global analysis, a local adaptive analysis adjusts the fundamental frequency to match the local image area. The local analysis proposes the use of a local dynamic range adjustment method to further improve spectral features estimation. Fourth, the matched filtering is based on the spectral features estimated in the local analysis, where an additional order-statistical filtering of the spectral features is introduced to increase the method's resilience towards noise. Finally, image segmentation separates fingerprint data from the background. This, taken all together, comprises the proposed new fingerprint enhancement system that automatically tunes its parameters according to each individual fingerprint image.

4. Implement of Proposed Method

Large regional contrast variation is quite typical for low quality fingerprint images which require a high dynamic range usage in order to not embed fingerprint ridges in the background. Hence, the SMQT-enhancement is performed using eight bits so as to avoid the risk of obstructing important data in heavily noisy fingerprint images. In addition, the eight-bit SMQT used in the preprocessing requires only a fractional amount of processing as opposed to other parts of the proposed method. Optimizing the processing load on this part of the algorithm yields therefore only an insignificant reduction of processing power but increases the risk of reduced performance.

The employment of the SMQT algorithm for fingerprint enhancement with $B = 8$ has been proposed in the project. While the idea is novel and is equivalent to the preprocessing step in this paper, it lacks an evaluation on fingerprint image databases with relevant metrics such as EER. Hence, it does not provide any major contribution in relation to which proposes SMQT for arbitrary gray scale image enhancement.

The aim with the SMQT is to remove the disparity between sensors due to gain and bias. Additionally, the extraction of the structure of the data should be done in an efficient manner. This structure extraction problem can be seen as the problem of dynamic range compression.

The finding of structures in data has been proposed before, for example the Census Transform which extracts a binary structure from the image. Producing digital images that render contrast and detail well is a strong requirement in several areas, such as remote sensing, biomedical image analysis and fault detection.

Performing these tasks automatically without human intervention is particularly hard task in image processing.

4.1. Successive Mean Quantization Transform

Let x be a data point and $D(x)$ be a set of $|D(x)| = D$ data points. The value of a data point will be denoted $V(x)$. The form of the data points can be arbitrary, that is $D(x)$ could be a vector, a matrix or some arbitrary form. The SMQT has only one parameter input, the level L (indirectly it will also have the number of data points D as an important input). The output set from the transform is denoted $M(x)$ which has the same form as the input, i.e. if $D(x)$ is a matrix then $M(x)$ is also a matrix of same size. The transform of level L from $D(x)$ to $M(x)$ will be denoted by

$$\text{SMQT}L\text{:}\ D(x) \rightarrow M(x)$$

The SMQTL function can be described by a binary tree where the vertices are Mean Quantization Units (MQUs). A MQU consists of three steps, a mean calculation, a quantization and a split of the input set.

4.2. Global Analysis

The magnitude spectrum of a fingerprint image typically contains a circular structure around the origin. The circular structure stems from the fact that a fingerprint has nearly the same spatial frequency throughout the image but varying local orientation. The circular structure in the magnitude spectrum has been used for estimating fingerprint quality. In a recent study, the circular spectral structure was exploited to detect the presence of a fingerprint pattern in the image. This paper employs that the radically dominant component in the circular structure corresponds to the fundamental frequency of the fingerprint image. This fundamental frequency is inversely proportional to a fundamental window size which is used as a base window size in our method.

The fundamental fingerprint frequency is estimated in the global analysis according to the following steps:

1. A new processing stage suppresses data outliers by a median filter.

2. A radial frequency histogram is computed from the magnitude spectrum of the median filtered image.
3. The fundamental frequency of the fingerprint is assumed located at the point where the radial frequency histogram attains its maximal value. The radial frequency histogram is herein proposed to be smoothed in order to reduce the impact of noise. The data outlier suppression is done by applying a median filter to the pre processed image that is SMQT enhanced image.

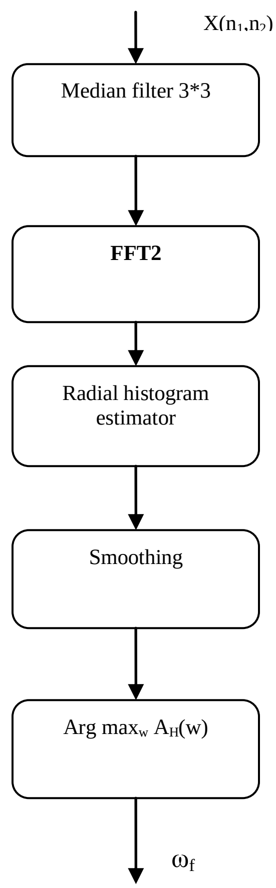

Figure 2. Processing blocks of Global Analysis

Later the radial frequency histogram is found for the median filter output that is applying the Fourier transform to the previous stage output and then the histogram is found for the image. The histogram gives the dynamic range adjusted image.

Dynamic range is the ratio between the largest and smallest possible values of changeable quantity, such as in signals like sound and light.

4.3. Local Analysis

The purpose of the local analysis is to adaptively estimate local spectral features corresponding to fingerprint ridge frequency and orientation. Most parts of a fingerprint image containing ridges and valleys have, on a local scale, similarities to a sinusoidal signal in noise. Hence, they have a magnitude spectrum with two distinct spectral peaks located at the signal's dominant spatial frequency, and oriented in alignment with the spatial signal. In addition, the magnitude of the dominant spectral peak in relation to surrounding spectral peaks indicates the strength of the dominant signal. These features are utilized in the local analysis. A similar method based on local spectral analysis is described in. However, according to the evaluation, there are distinct performance improvements in the proposed method.

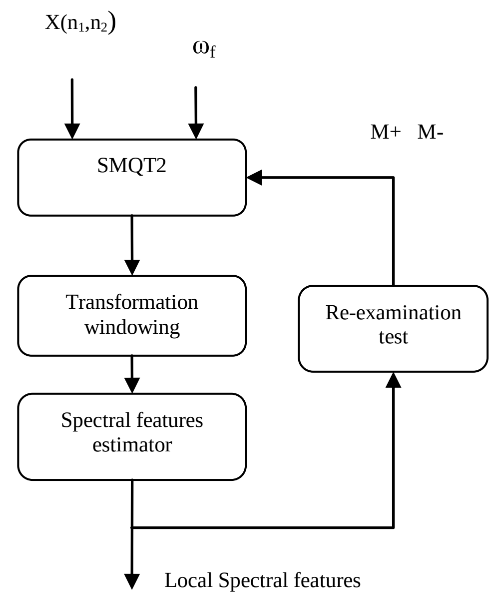

Figure 3. Processing Blocks of Local Analysis

The fundamental area size L_f computed is used as a fundament in the local analysis. The size of the local area in the local analysis is M × M, where M is an odd-valued integer computed as:

$$M = 2[(k. L_f)/2 +1] – 1$$

Where, the parameter k is a design parameter that controls the number of fundamental periods enclosed by each local area. Due to the local variability of a fingerprint, for example in regions around deltas, cores and minutiae where the fingerprint ridges are curved or when the local ridge frequency deviates from the estimated fundamental frequency ω_f, two additional local area sizes are introduced. A larger local area size, denoted as × M+ , where M+ = (1 + η) ·M, and a smaller local area size, denoted as M− × M− , where M− = (1 − η)· M, are considered here. Note that both M_+ and M_- are forced to be odd-valued integers. The design parameter η ∈ [0, 1] defines the change, i.e., growth and shrinkage, of the larger and smaller area sizes in relation to the nominal local area size. It is stressed that all parameters used herein are functions of the larger and smaller area sizes in relation to t the automatically estimated fundamental area size L_f. Hence, the size of the local area, including the larger and smaller area sizes, automatically adapt to fingerprint and sensor variability.

The following steps are carried out for each local area in the local analysis:

1) A local dynamic range adjustment is proposed to be applied to each local area.

2) A data-driven transformation is conducted in order to improve local spectral feature estimation. The data for each local area is windowed and zero padded to the next larger power of two.
3) A local magnitude spectrum is computed and the dominant spectral peak is located from which the local features frequency, orientation and magnitude are estimated.
4) A test if the local area needs to be re examined, using a larger and a smaller size of the local area, is conducted. Steps 1–3 of the local analysis are repeated using these alternative area sizes if a re examination is required.

Applications

Fingerprint enhancement plays a vital role in networking and communication applications. The use of received signal strength based radio fingerprints for energy efficient inter-frequency small cell discovery. The fingerprint data is optimized by removing redundant information and sent to the mobile station by the network on entering a cell for the first time within a specified time period. The fingerprint data is further used for small cell discovery. We evaluate the performance of the scheme using system level simulations in a heterogeneous network scenario considering the power consumed for finding small cells and the fraction of offloading potential utilized. System level simulations are conducted using 3GPP LTE-Advanced heterogeneous network setting using a realistic movement model. We also consider the energy consumed for signaling measurement reports from a mobile station to the base station and the simulations done show that significant energy savings can be obtained by using the evaluated scheme without compromising the available offloading potential. The evaluated scheme enables autonomous mobility and small cell discovery within a cellular network.

In developing an embedded system, which is used for ATM security applications. In these systems, Bankers will collect the customer finger prints and mobile number while opening the accounts then customer only access ATM machine. The working of these ATM machine is when customer place finger on the finger print module when it access automatically generates every time different 4-digit code as a message to the mobile of the authorized customer through GSM modem connected to the microcontroller. The code received by the customer should be entered by pressing the keys on the touch screen. After entering it checks whether it is a valid one or not and allows the customer further access.

An approach on secure fingerprint authentication and matching techniques to implement in ad-hoc wireless networks. This is a difficult problem in ad-hoc network, as it involves bootstrapping trust between the devices. The solution to this problem is which provides fingerprint authentication techniques to share their communication in ad-hoc network. In this approach, devices exchange a corresponding fingerprint with master device for mutual communication, which will then allow them to complete an authenticated key exchange protocol over the wireless link. The solution based on authenticating user fingerprint through the master device and this master device handshake with the corresponding slave device for authenticating the fingerprint all attacks on the wireless link, and directly captures the user's device that was proposed to talk to a particular unknown device mentioned previously in their physical proximity.

Fingerprint enhancement is a crucial step in fingerprint recognition. The accuracy of the recognition algorithm directly depends on the accurate extraction of features which is achieved through a series of image enhancement steps. Unfortunately, the fingerprint enhancement process consists of a series of computationally expensive image processing techniques. This results in slow recognition algorithms. Researchers have examined ways of improving the performance of fingerprint enhancement algorithms through parallel processing. The majority of such techniques are architecture- or machine-specific and do not port well other platforms. A cheaper and portable alternative through the utilization of mixed-mode distributed and parallel algorithms that make use of multicore clusters for processing strength. It tackles a few design concerns encountered when distributing image processing operations. One such concern is dealing with pixels along the borders of the partitioning axis. The other is distributing data that needs to be processed in blocks rather than pixel-wise.

5. Simulation Results

In this chapter the simulation results of the project are presented and the block wise outputs as well. As the input fingerprint image is generally affected by some random noise, we ought to reduce the same to make the further blocks comfortable in enhancing and processing the image. On the other hand the fingerprint images are generally unable to utilize the entire dynamic range available for it. The dynamic range of the finger print image should be adjusted. So, pre-processing block is needed for this purpose.

Figure 4. Input Finger Print Image

Figure 5. Output of Pre Processing Stage

Figure 6. Output of Median Filter

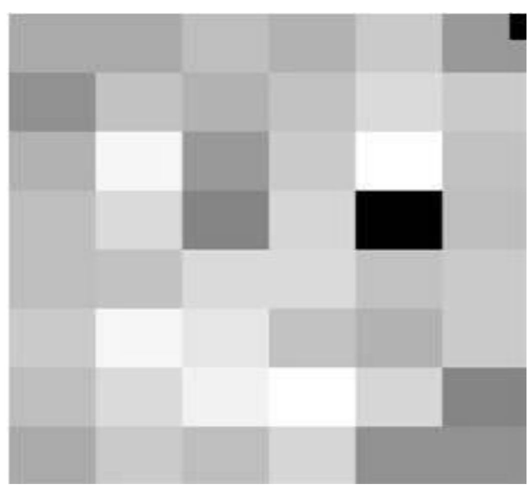

Figure 7: Frequency Image of Finger Print

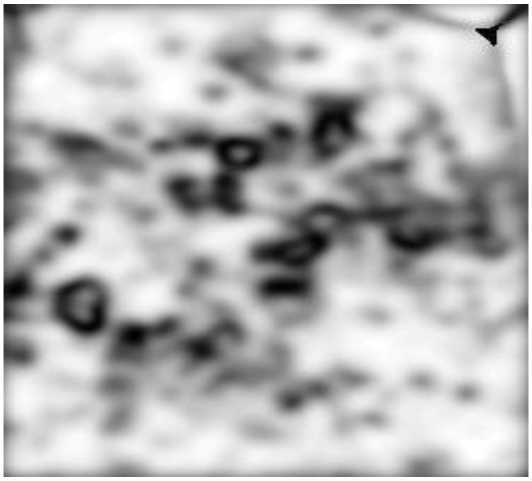

Figure 8. Quality Map of Local SMQT

Figure 9: Result of Segmentation

The output image is the element-wise product of the outputs from segmentation and matched filtering blocks. Figure 5.7 shows that the output fingerprint image has better visibility and enhanced efficiently so that one can obtain the matching reliable characteristics of the fingerprint image.

Below, for easy identification the input fingerprint image and the enhanced output images are shown making a comparison between them.

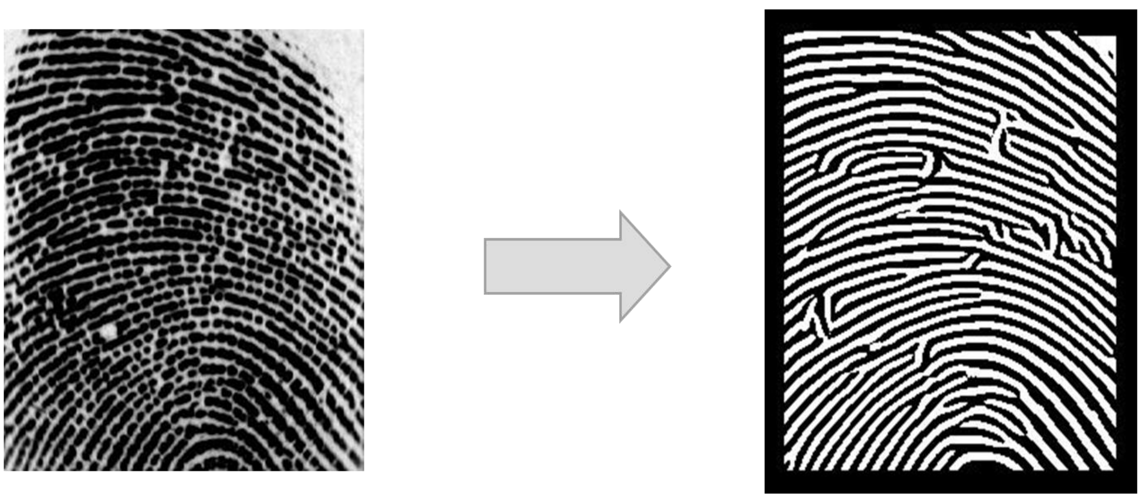

Figure 10. Input and Output Images of the Proposed Method

6. Conclusion and Future Scope

This work presents an adaptive fingerprint enhancement method. The method extends previous work by focusing on pre processing of data on a global and a local level. A pre processing using the non-linear SMQT dynamic range adjustment method is used to enhance the global contrast of the fingerprint image prior to further processing. Estimation of the fundamental frequency of the fingerprint image is improved in the global analysis by utilizing a median filter leading to a robust estimation of the local area size. A low-order SMQT dynamic range adjustment is conducted locally in order to achieve reliable features extraction used in the matched filter design and in the image segmentation. The matched filter block is improved by applying order statistical filtering to the extracted features, thus reducing spurious outliers in the feature data. The proposed method improves the performance in relation to the previous methods, and this is particularly pronounced on fingerprint images having a low image quality. The evaluation results indicate that the method is able to adapt to varying fingerprint image qualities, and it is stressed that the proposed method has not been tuned in favour towards any quality of fingerprint image. The proposed algorithm is insensitive to the varying characteristics of fingerprint images obtained by different sensors.

A possible future research direction is to perform a detailed and systematic analysis of the impact of the different chosen design parameters. Furthermore, various optimizations of the implemented processing steps could reduce the number of instructions required by the proposed method.

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