Chapter 7

Conclusion and Experimental Results
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7.1 Introduction

This chapter summarizes the results obtained at various stages of this research work validated on public domain FVC2002 databases and another set of live-scan fingerprint images collected using an optical fingerprint reader from a heterogeneous population. Conclusion and future work have also been presented.

7.2 Experimental results

Experiments at the first stage evaluated the performance of the proposed preprocessing methodology (Algorithm 1) used in this work. Gaussian, Butterworth and Bandpass filters generated directly in the frequency domain had been considered for analysis in order to determine the best filter that can be applied to fingerprint images for enhancement to have better match accuracies. The parameters used for performance analysis of the proposed technique are: Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE) and computation time. The results exhibited that the Gaussian Bandpass filter having lower and higher cut-off frequencies 130 and 225 respectively with PSNR value 26.4865db is best suited to reduce noise and smooth the small holes (Figure 3.9 and Table 3.1).

Comparative experimental analysis of three existing fingerprint core point detection techniques based on Poincare index (PI) computation, Complex Filters (CF) and Multi Scale analysis of Orientation Consistency (MSOC) using orientation field estimate regularized by non-
adaptive and adaptive neighborhood analysis had been performed to detect the optimum reference point detection technique in terms of consistency and detection accuracy for subsequent classification and matching stages. Accepted number of Reference Points (ARP), False number of Reference Points (FRP) and number of fingerprints where reference points goes undetected (UD) were the performance indicators used in this analysis. Obtained results from the experimental study indicate that, localization of reference point based on MSOC using adaptive neighborhood orientation regularization method (Algorithms 4 & 7) is consistent with high accuracy for all classes and qualities of fingerprints with ARP 93.27%, FRP 5.27% and UD 1.45% (Table 4.1).

The proposed fingerprint classification system based on the novel fingerprint representation (DVF) (Algorithm 8) proposed in this work using MLP neural network had been tested on 1450 fingerprint images. 815 fingerprints were chosen for training and 635 images for testing randomly. The number of hidden neurons was determined experimentally. Experiments were conducted for three different input feature vectors consisting of i) DVFs computed along the 16 radial directions (16 input neurons) ii) DVFs computed along the 16 radial directions and the radial direction with least mean Absolute Sine Component (ASC) value (17 input neurons) and iii) DVFs computed along the 16 radial directions and the radial directions with least two mean ASC values (18 input neurons) (Table 5.1). An accuracy of 96.9% with 3.1% error rate has been achieved with 18 input neurons, 20 hidden neurons and 5 output neurons corresponding to the five classes as depicted in the confusion matrix (Table 5.2). The classification accuracy of the proposed method had also been compared with the reported accuracy of other existing techniques for 5-class scheme validated on the same dataset (Table 5.4).
False Acceptance Rate (FAR), False Rejection Rate (FRR), Equal Error Rate (EER) and matching time were the metrics used to measure the performance of the suggested hierarchical fingerprint verification system (Algorithm 10). The efficiency of the matching algorithm at the first level based on non-minutiae feature DVFs was compared with the Fingercode matching scheme as proposed in [JPHP00]. It was observed that when FAR is 0.015%, FRR is 19.2% and Equal Error Rate (EER) is 1.82% (Table 6.2 and Figure 6.11). The overall accuracy of the proposed matching system by combining results of independent matchers based on global DVFs and local LS fingerprint representations has significantly improved with decreased error rate (EER value - 0.65%) in less processing time (Figure 6.13 and Table 6.4). The matching system brought forth had also been compared with other existing minutiae-based systems (Table 6.3) and the corresponding ROC curves is shown in Figure 7.1.

![Figure 7.1: Comparison of existing methods using ROC curves for FVC2002 database](image-url)
7.3 Contributions of the Research

The objectives of this research work mentioned in Section 1.5 have been implemented successfully taking into consideration the limitations of prevailing algorithms in dealing with very low-quality fingerprint images and robustness to rotation and translation. As a single fingerprint enhancement technique is not sufficient to tackle all types of noises and non-linear distortions present in the sensed fingerprint, apart from the initial enhancement technique applied for improving the clarity and legibility of fingerprints, regularization techniques have also been carried out at each stage prior to the feature extraction process. From the obtained results of the proposed efficient and robust classification and matching systems, it is evident that:

- The enhancement and smoothing methods employed at stages previous to the feature extraction procedure has enabled the task of localizing a unique reference point accurately for all classes of fingerprints. However, for a negligible percentage of fingerprint images in the database whose core point is missing as shown in Figure 7.2, the reference point was not detected that has affected the matching and classification process.

- The novel fixed size feature vectors DVFs and LSs constructed in this work based on the global and local attributes of fingerprints respectively are compact and consumes only a few kilobytes of storage space and hence can be utilized in biometric applications such as smartcards where storage is at its premium.

- The designed five-class fingerprint classification system based on global DVFs using a neural network exhibits a high accuracy of 96.9% that has a time complexity of O(n).
The integration of DVF features with local structures (LS) significantly improved the matching accuracy with low EER 0.65%. The verification system is robust to noise and transformation to a great extent and has also matched partial fingerprints with missing delta points.

Based on the criticality of the applications in terms of matching accuracy, the devised verification system is flexible enough to modify the thresholds or constraints of the percentage of fingerprints being matched.

![Fingerprint images from the database with missing core points](image)

**Figure 7.2: Fingerprint images from the database with missing core points**

### 7.4 Conclusion

This dissertation has concentrated on proposing algorithms that operate directly on grayscale fingerprint images as a considerable amount of information is lost during the process of image binarization. This work has also focused on representing fingerprints by features that can easily be extracted, stored in a compact fashion that contain distinctive information about the fingerprint.

The developed classification module can considerably improve the searching process in recognition systems and the suggested verification technique can be deployed to control physical device access by integrating
fingerprint recognition into laptops, tablets, smartphones and other electronic devices that have personal and sensitive data. The proposed models demonstrated good performance compared to many other existing systems with less computational complexity and high accuracy.

7.5 Future Work

This research work can be expanded in the following areas:

- The current implementation of the Directional Variance Features (DVFs) in verification is not invariant to large perturbations due to rotation, hence this problem need to be addressed by adding more features in the current representation based on global characteristics so as to avoid a second level matching process as proposed using minutiae as extraction of minutiae points are not reliable in very low-quality fingerprint images with corrupted ridge patterns.

- The proposed matching algorithm (one-to-one) can be further improvised and applied for fingerprint identification system (one-to-many)

- To device an effective technique for securing stored fingerprint templates taking into consideration the security issues and specific vulnerabilities existing in fingerprint systems.