Analyzing Contemporary Approaches in Fingerprint Classification

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ABSTRACT

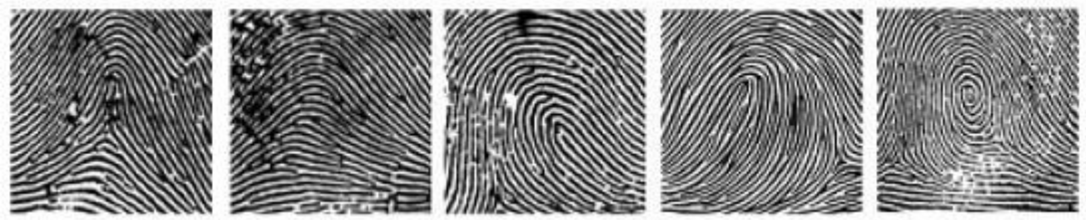
Automated fingerprint recognition has emerged as a widely utilized tool for personal identification and various biometric applications, owing to its dependable and distinctive characteristics. Fingerprint classification stands out as a crucial task in the context of large-scale fingerprint recognition systems. This task is inherently challenging due to factors such as limited interclass variability, substantial intraclass variability, the presence of noise, and the inherently ambiguous nature of fingerprints. Effectively addressing the complexities of fingerprint image classification requires sophisticated pattern recognition solutions. A precise classification algorithm holds the potential to significantly reduce the number of comparisons required during fingerprint retrieval, thereby expediting the identification process. Over the last few decades, a substantial body of research has been dedicated to devising techniques for distinguishing different fingerprint classes. This paper presents a comprehensive review of existing approaches employed in addressing fingerprint classification challenges. The discussion encompasses key issues, design considerations, and the performance evaluation of various techniques within the realm of fingerprint classification systems.

Keywords — Pattern Recognition, Classification Fingerprint Retrieval, Identification, Classification system.

1. INTRODUCTION

Within the expansive landscape of fingerprint identification systems, the necessity arises for comparing an individual's fingerprints with the entire database to pinpoint corresponding individuals in storage. The adoption of a classification approach holds immense potential to substantially diminish the number of comparisons during fingerprint retrieval, consequently mitigating the response time in the identification process. With the proliferation of fingerprint image databases, there is a growing need for an efficient method of classifying fingerprints. Traditionally, the widely used classification method is rooted in Henry's classification, encompassing eight classes: Plain Arch, Tented Arch, Left Loop, Right Loop, Plain Whorl, Central-Pocket Whorl, Double Loop Whorl, and Accidental Whorl.

Figure 1 illustrates the fundamental categories of fingerprint classes.



(a) (b) (c) (d) (e)

Figure 1 Fundamental categories of fingerprint classes: (a) Tented Arch (b) Arch (c) Right Loop (d) Left Loop (e) Whorl.

Automated fingerprint classification presents a formidable pattern recognition challenge due to various factors. Notably, the challenge is exacerbated by significant intraclass variation and minimal interclass variation in fingerprint images. Instances arise where prints from one class bear resemblance to prints from another class, while prints from the same class may exhibit pronounced differences. Another substantial hurdle involves the presence of noise in fingerprint images, intensifying the complexity of the classification task. Random noise and skin condition-induced effects, such as dryness, sweat, dirt, and disease, can introduce errors in fingerprint images. Addressing this challenge necessitates preprocessing steps to enhance the original ridge patterns in the fingerprint image. Ambiguous fingerprints pose an additional challenge, with some prints defying classification even by human experts.

A robust fingerprint classification system must devise strategies to handle such cases, such as assigning them to an "anomalies" class or outright rejection. Selecting an accurate fingerprint classification technique hinge on the number of classes and the natural distribution of fingerprints.
Unfortunately, the number of classes is often limited, and the distribution is non-uniform due to the presence of ambiguous fingerprints. Figure 2 outlines the process for fingerprint classification systems.

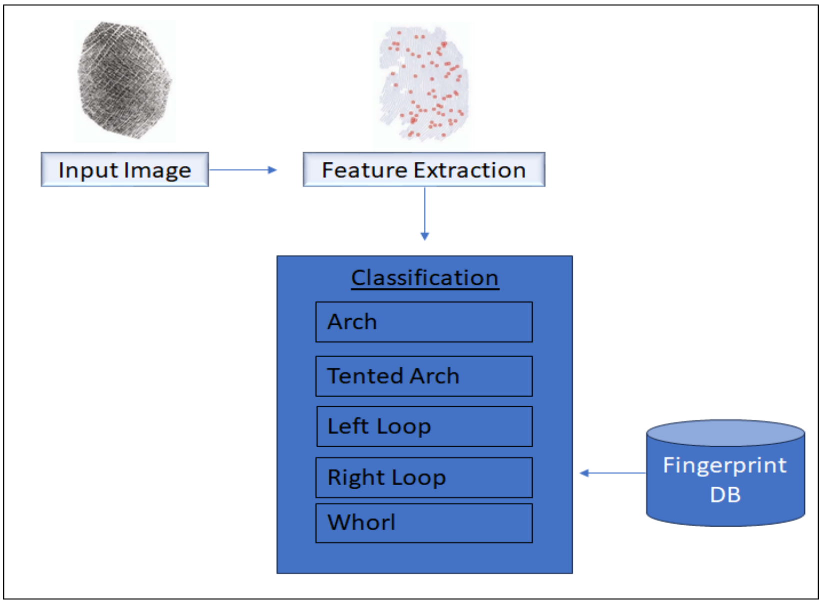


Figure 2. Process for fingerprint classification systems.

The crux of designing a fingerprint classification system lies in determining which features to employ and how these features can effectively categorize fingerprints. Beyond reducing fingerprint comparisons, fingerprint classification enhances the overall efficiency of the identification system.

2. RELATED WORK

The use of entire fingerprint images in classification may prove overly restrictive for numerous applications. Researchers have developed a variety of fingerprint classification approaches over the past thirty years, proposing at least four major methodologies: heuristic-based, structure-based, frequency-based, and syntactic approaches. The subsequent section explores these general approaches.

I. Heuristic Approach

Singular Point Based Method

Some rule-based approaches rely on singularity features, global ridge structure information, and combinations of singularity and ridge features. Singular points, introduced by Henry, are crucial for accurate fingerprint classification, focusing on detecting and extracting core and delta points. Fitz and Green [1] proposed a Fourier transform method for core point localization, while Rao and Black [2] reported a syntactic method using tree grammar for singular point extraction. Karu and Jain [3] developed a six-class fingerprint classification system based on heuristic approaches. Another approach involves pruning based on neighbours and a relaxation method for noise reduction to locate cores and deltas. The Poincare Index is exploited for determining the type and position of singular points, leading to a coarse classification. Kawagoe and Tojo [4] proposed this method early on. Srinivasan and Murthy [5] used structural information chosen from the directional histogram of the directional image of a fingerprint. Zhang et al. [6] suggested a corner detection method to identify singularity regions, with the grey level of ridges tracked to determine the position of singular points. Tong et al. [7] proposed an indexing fingerprint based on location, direction, estimation, and correlation of singular points, while Liu Wei [8] used delta direction and singularities to partition fingerprint classes. Current classification methods, whether structural or network-based, predominantly rely on extracting singular points in fingerprint images [6, 9, 10].

Global Ridge Structures

Another heuristic classification system is based on the representation of ridge structures as global features, often reliably extracted even from noisy images. Chong et al. [11] utilized the global geometric shape of fingerprints to calculate the orientation of fingerprint images. Note that the classification system proposed by the authors involves five fingerprint classes. A more robust technique, proposed by Hong and Jain [12], introduced a rule-based classification algorithm using the number of singularities alongside the global ridge representation in fingerprint images. The combination of these features leads to better performance than methods found in [3]. According to [14] and [12], ridge shape can be incorporated with singularity information to aid classification. Jun Li et al. [15] combined orientation and singularity information as input features for fingerprint classification, while Liu et al. [16] utilized some curve features of ridgelines alongside singular points.

II. Structural Approach

Syntactic Approaches

Structural pattern recognition for fingerprint classification involves two methods: syntactic classification and graph matching.

A syntactic method establishes a connection between the structure of input data features and production rules. Each fingerprint class is associated with a set of rules defined as grammar, generating sequences corresponding to the class. Recent research has proposed approaches that do not rely on singular points as crucial aspects for fingerprint classification.

Moayer and Fu [17] introduced a syntactic approach using context-free grammars divided into seven classes as fingerprint patterns. They experimented with various grammars, including stochastic grammars and tree grammars. Rao and Balck [18] proposed an approach based on the analysis of ridge line flow, labeling connected lines according to direction changes. This results in a set of strings processed through grammars or string-matching techniques for the final classification [19]. Chang and Fan [20] developed a classification scheme utilizing regular expressions to describe fingerprint ridge structures. Syntactic approaches, while robust in the presence of noise and invariant to translations and rotations, require complex grammars, making them prone to instability due to the diversity of fingerprint patterns. These methods grapple with large intraclass and small interclass variations, demanding grammars capable of recognizing diverse sequences within the same class and differentiating very similar sequences from different classes.

Graph Matching

Maio and Maltoni [21] proposed a system classifying fingerprints based on relational graphs, creating a model graph for each fingerprint class with a typical structure. Further research by [8] employed a template-based matching method to guide orientation field partitioning using dynamic masks. This approach effectively handles partial fingerprints where singular points may not be available. Relying solely on global structural information, it can also work on noisy images. The introduction of a relational graph on the directional field is found in [22].

Relational graph approaches exhibit properties like invariance to rotation and displacement, enabling the handling of partial fingerprints. However, robustly partitioning the orientation image into homogeneous regions, especially in poor-quality fingerprint images, poses challenges. The relational graph for tented arches, left loops, and right loops may look similar, but the approach's strength lies in recording the degree of similarity with three classes, providing valuable discriminatory information. In this context, relational graph approaches prove beneficial for continuous classification rather than forcing the print into a single arbitrary category.

III. Neural Approach

Multilayer Perceptron-Based Techniques

Many proposed neural network techniques are grounded in multilayer perceptrons, utilizing orientation image information as input features. Kamijo [23] introduces a pyramidal architecture comprising several multilayer perceptrons, each trained to recognize fingerprints from different classes. Bowen [24] employs the location of singularities and orientation image for training two disjoint neural networks, while [25] adapts neural network computing on directional images.

NIST researchers [26] utilize a multilayer perceptron for classification after reducing the dimensionality of the feature vector. Improved versions of this method are presented in [27], incorporating specific changes and optimizations in the network architecture. Neto and Borges [28] develop a neural network classification system using wavelet features, although their sensitivity to rotations and translations limits their usefulness for fingerprint classification. Another approach uses a fuzzy-network classifier [29] to classify fingerprints based on singularity features, encompassing core and delta points, orientation of core points, relative positions, and the global direction of the orientation field. [30] describes a fingerprint classification system using artificial neural networks, predominantly relying on orientation field vectors for classification. Dubravko [31] introduces a neural network classification system using the homogeneity structure of a fingerprint's orientation field as the input vector.

IV. Statistical Approach

K-Nearest Neighbour and k-Means Classifier

In statistical approaches, a fixed-size numerical feature vector is derived from each fingerprint, and a general-purpose statistical classifier, such as the K-nearest neighbour, is employed for classification [19]. [1] proposes a method based on Fourier transform for feature extraction and introduces the first step of a two-stage classification technique using the k-nearest neighbour rule.

Wang et al. [33] investigate the use of a k-Means classifier, with many researchers directly utilizing the orientation image as a feature vector. In [33], orientation vectors in the area surrounding a fingerprint's core are used as features. Support vector machines (SVMs), a relatively recent classifier based on statistical learning theory, have gained attention. Yao et al. [34] apply SVMs as a classifier on fingerprint features, leveraging their strong ability to classify high-dimensional vectors.

3. CONCLUSION

Recent advancements in automatic fingerprint classification systems have spurred extensive research efforts in this domain. The imperative task of classifying all fingerprint images in a database based on predefined criteria holds significant importance for addressing accuracy and identification speed challenges. Various approaches have been explored over the years, differing in the features employed to describe the significance of fingerprint image classification. However, there remains ample room for enhancing algorithms, particularly in pre-processing steps.

Our investigation reveals a diverse array of techniques and features employed in fingerprint image classification. A comprehensive comparative study on feature extraction for fingerprint classification is detailed in [35]. Despite progress, as highlighted by [36], there are lingering research opportunities linked to system performance, especially concerning the rejection of a high percentage of input. The challenge persists due to the inability of many classification methods to meet stringent requirements, such as classification accuracy.

Future studies in fingerprint classification systems may benefit from employing combinations of features. As suggested by [36], fingerprint singularities are considered the optimal features for classification. However, extracting core and delta points from noisy images poses a challenge. Additionally, orientation fields and ridge structure features can be reliably calculated even in the presence of noise, though they may lack the robustness of singularities. Future research endeavours should explore the relative advantages among different fingerprint representations.

While different classifiers demonstrate efficacy with distinct feature sets, the amalgamation of classifiers is anticipated to yield more accurate results in the future.

4. FUTURE WORK

An ongoing challenge in fingerprint classification revolves around the lack of robustness when confronted with poor-quality images. Recognizing the significance of this issue and the pressing need for performance enhancements, our research is poised to delve deeper into this area, with a specific focus on improving the classification of low-quality fingerprints. Our forthcoming study aims to provide comprehensive insights into addressing the intricacies of poor-quality fingerprint images, particularly concentrating on refining the pre-processing steps to enhance overall image quality. The proposed work endeavours to tackle the challenges posed by poor quality and noise in fingerprint images. Designing a system that exhibits robustness in handling varying image qualities is a key objective, ultimately contributing to enhanced performance in fingerprint classification systems.

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