A Survey on Fingerprint Classification Techniques

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Abstract*—Fingerprints have been used as a method of identifying individuals due to the favorable characteristics such as ”unchangeability” and ”uniqueness” in an individual’s lifetime. In recent years, as the importance of information security is highly demanded, fingerprints are utilized for the applications related to user identification and authentication. The main objective of this paper is to review the extensive research that has been done on fingerprint classification over the last four decades. In particular, it discusses the fingerprint features that are useful for distinguishing fingerprint classes and reviews the methods of classification that have been applied to the problem.

***Index Terms*—Biometrics, Fingerprint classification, Orientation fields, Minutiae Point, Core Point, Delta Point**

I. INTRODUCTION

Biometrics is the automatic identification of an individual based on his or her physiological or behavioural characteristics. The ability to accurately identify or authenticate an individual based on these characteristics has several ad- vantages over traditional means of authentication such as knowledge-based (e.g., password) or token-based (e.g., key) authentication [1]. Due to its security-related applications and the current world political climate, biometrics has recently become the subject of intense research by both private and academic institutions. Fingerprint biometrics is already playing an important role in the securing of information: personal, confidential and sensitive. This can largely be attributed to two main factors; one technical and the other one not so technical. The technical factor is that fingerprint biometric systems are highly accurate when measured against systems that make use of other biometrics. A few examples of these other biometrics include speech, iris, hand geometry and palm veins. The non- technical factor is that fingerprint biometric systems carry a positive public perception, that is, they are generally accepted by the consumers. This is because consumers find these systems easy to use and less invasive.

Fingerprint recognition is one of the most popular and well accepted biometric recognition techniques for personal identification and authentication. Fingerprints are reliable because of their consistency and uniqueness over time. A fingerprint template contains many features. These features could be categorized into global and local levels. Global level features determine how a fingerprint looks like. Therefore, they are useful for fingerprint classification. For example, a fingerprint could be a left loop type because its ridge lines form a loop pointing to the left side. Normally, fingerprints could be classified into 4 types which are: left loop, right loop, and whorl and arch types. However, global features can be only used for rough classification of fingerprints, but local features are more accurate for fingerprint matching. The most important local feature in a fingerprint is minutiae point.

Fingerprint matching is usually carried out at two different levels. At the coarse level, fingerprints can be classified into six main classes: arch, tented arch, right loop, left loop, whorl and twin loop .The fine- level matching is performed by extracting ridge endings and branching points, called minutiae, from a fingerprint image. The similarity between two fingerprints is determined by comparing the two sets of minutiae points. Although the coarse classification does not identify a fingerprint uniquely, it is helpful in determining when two fingerprints do not match. For example, a right loop image should be matched with only other right loop images in the database of fingerprints. When fingerprints from all the ten fingers are available, the coarse level classification of these ten prints drastically reduces the proportion of database images to be matched at the finer level. A human expert can perform coarse-level classification of fingerprints relatively easy. For an automatic system, the problem is much more difficult because the system must take into account the global directions of the ridges as well as their local connectivity to make its decision.

II. FINGERPRINT CLASSES

Fingerprints can be categorized based on their global pattern of ridges and valleys. Galton originally proposed the use of three fingerprint classes: the arch, the whorl and the loop. Henry subdivided the arch category to include the plain arch and the tented arch. He also defined two types of loops: ulnar and radial, also known as right loops and left loops respectively. He also added classes that are combinations of arches, loops and whorls: central pocket loops, twin loops and accidentals. Henry used the accidental class to describe the small number of fingerprints that are ambiguous and do not fall clearly into any of the other categories [5]. The distribution of the classes in nature is not uniform. Central pockets, twin loops, and accidentals are very rare so they are often ignored for classification purposes.

Henrys classification (and others based on it) is known as exclusive because they partition fingerprints into mutually exclusive categories. Many large-scale fingerprint verification systems are designed to only match a print against others from the same class. This has several disadvantages [5]. First of all, there are some fingerprints that are ambiguous and cannot be classified even by a human expert. In these cases it is unclear which fingerprint classes the ambiguous print should be matched against. Furthermore, there is always the possibility of misclassification due to noise or an error in the system. In these cases, if no match is found in the erroneous class the entire database will need to be searched. Finally, even assuming the classification is robust, this does not always significantly reduce the number of one-to-one matches. A large majority (almost 95%) of fingerprints fall into only three classes. When an individual is being identified using all ten of their fingerprints (known as ten-print based identification), knowing the class of all ten fingers greatly reduces the number of matches that are necessary.

However, when only a single fingerprint is available (such as latent fingerprints) the print will almost certainly need to be matched against a large segment (usually about 1/3) of the database. Continuous classification addresses some of the shortcomings of exclusive classification. Instead of being represented by a single class, fingerprints are represented by a feature vector containing important distinguishing characteristics of the print [4]. The similarity of two fingerprints can be defined as the Euclidean distance between them in the feature space and query fingerprints are matched against all other prints that fall within a given radius. This immediately resolves the problem of which prints should be matched against an ambiguous fingerprint.

III. FINGERPRINT CLASSIFICATION TECHNIQUES

This section discusses some of the classification methods that have been applied to the problem. The section Structural features present structural classification approaches, namely syntactic pattern recognition and graph matching. Various heuristic approaches based on singularities and ridge structures are discussed in the section the heuristic approach. The section the neural approach surveys the existing applications of neural networks to fingerprint classification and the section other approaches reviews miscellaneous approaches to classification. Finally, complete content and organizational editing before formatting. Please take note of the following items when proof reading spelling and grammar.

Syntactic Pattern Recognition

Syntactic pattern recognition an analogy is drawn between the structure of the input data's features and the syntax of a language. Complex patterns are decomposed into simple sub-patterns known as primitives that comprise the alphabet of the language. The input data is represented by a sequence of primitives, which is considered to be a sentence of a language. Every class has an associated set of rules (or grammar) that describes how to build new sequences (or sentences). Classification is performed by determining which grammar most likely produced a given input sequence.

Graph Matching

Given two graphs as input, graph matching algorithms attempt to determine whether or not the graphs are isomorphic. In the section Structural features a method for representing a fingerprints topology using relational graphs is presented, and Maio and Maltoni have proposed a system that classifies fingerprints based on these graphs. For each fingerprint class a model graph is created that has a structure typical of that class. Since there will inevitably be some variation among graphs from the same class, Maio and Maltoni propose to use an inexact graph matching algorithm. This would allow one to define a distance between two graphs that could be used as the basis for either an exclusive or continuous classification scheme [4].

Singularities

Singularities define singularities (core and delta points) and discuss various methods of detecting and extracting them from fingerprint images. Henry introduced singular points because of their usefulness for classifying fingerprints. For example, he noted that in loops... there is one delta. Systems based on singularity rules work very well if the singularities are accurately detected. They are not sensitive to rotations and translations and fingerprints [3].

Global Ridge Structures

Several methods have been proposed to extract and represent the ridge structures that are found in a fingerprint and it is possible to use these features as the basis for a heuristic classification system. One advantage of this approach is that ridge structures can be global features, and therefore can often be reliably extracted even for noisy images [1].

Hybrid Classifiers

It is well known in pattern recognition that all classifiers have strengths and weaknesses when compared to each other. In other words, there is no known classier that consistently outperforms all other classifiers on all problems. Therefore, it is often beneficial to combine classifiers to exploit their relative advantages. When two different classifiers are used in conjunction it is known as a hybrid classifier [2].

IV. CLASSIFICATION CHALLENGES

There are several challenges to the classification of fingerprints that are specific the fingerprint domain. These are important issues that need to be addressed by any fingerprint classification system. Prints from the same finger will be slightly different every time they are captured for several reasons, and classification systems must be designed to be robust when dealing with these variations[1][6]. There are several causes for this variation. For example, every time a finger is pressed against a surface, it is applied with a certain amount of pressure at a well-defined angle, and these parameters vary from time to time, resulting in a different portion of the print being captured. Consequently, fingerprint classifiers should not be sensitive to translations or rotations of fingerprints. Random noise and other effects caused by the skin conditions (e.g., dry, sweaty, dirty, and diseased, etc.) can cause errors in the fingerprint image. It is important for classification systems to recover the original ridge patterns, and therefore preprocessing is usually conducted to enhance the fingerprint image.

Another major challenge is related to fingerprint class variation. The majority of classification schemes use 5 classes. However, there is a wide variety of possible patterns within each class. Furthermore, in some cases prints from one class can appear very similar to prints from another class. In other words, there is large intra class variation and small interclass variation. This is the most significant factor that makes the fingerprint classification problem so difficult, and is one of the motivations for developing continuous classification schemes. Ambiguous fingerprints are a related issue. In some cases, a fingerprint will have properties from more than one class. A fingerprint classification system must devise a method for dealing with these prints, such as having an anomalies class or rejecting them outright.

V. CONCLUSION

Automated fingerprint classification is an inherently difficult problem that has yet to be adequately solved. The use of directional patterns has recently received more attention in fingerprint classification. It provides a global representation of a fingerprint, by dividing it into homogeneous orientation partitions. With this technique, the challenge in previous works has been the complexity of the pattern templates used for classification. In addition, incomplete fingerprints are often not accounted for. A rule-based technique using simplified rules is proposed to overcome the challenges faced by previous pattern templates. For further works, rules for incomplete fingerprints can be extended on, since the method thus far does show potential in addressing fingerprints with missing singular points. Analyzing the global representation of the fingerprint that proved to be advantages, as the rules are invariant to rotation and have the potential to address issues of incomplete fingerprints.

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