Fingerprint Image Classification and Retrieval using Statistical Methods

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1. Title of the Thesis and Abstract

1.1 Title of the Thesis

Fingerprint Image Classification and Retrieval using Statistical Methods.

1.2 Abstract

Human fingerprints are popular biometrics due to its characteristics like universality, uniqueness, permanence, collectability and acceptability. Fingerprints are rich in details which are known as minutiae, which can be used as identification marks to uniquely identify the fingerprint for various purposes. There are four basic patterns of fingerprint ridges; arch, left loop, right loop and whorl.

Fingerprint classification is an important indexing scheme to narrow down the search of fingerprint database for efficient large-scale retrieval. It is still a challenging problem due to the intrinsic class ambiguity and the difficulty for poor quality fingerprints. Fingerprint retrieval is a pre-requisite step for many applications like recognition and registration. Feature extraction plays a very important role in retrieval process. The work presented in this research has two phases; classification and retrieval. In classification phase, scale and rotation invariant features are extracted to enhance the local information from the fingerprint images for powerful representation. These features strongly represent the similarities of fingerprint images of the similar class. Classification is carried out by applying these features in classification models. The retrieval phase match the fingerprint image features using distance matching methods to retrieve similar images from the class declared from classification phase. The experimental results and comparisons on FVC2000, FVC2002, FVC 2004 and NIST-4 databases have shown the effectiveness and superiority of the proposed method for fingerprint classification and retrieval.
2. Brief description on the state of the art of the research topic

The identification of a person with an AFIS (automated fingerprint identification system) requires a comparison of his/her fingerprint with all the fingerprints in a database [1]. This database may be very large in many forensic and civilian applications, which leads to long processing time and deteriorated accuracy; hence it is unsuitable in real time applications. A common strategy to speed up the search is to divide the fingerprint database into a number of groups that have similar properties. Fingerprint classification that assigns a fingerprint to a class (based on predefined classes) is an effective way.

Fingerprint classification has generated great interest due to its importance and intrinsic difficulty and there are number of approaches proposed in the literature. A typical fingerprint classification algorithm usually extracts a representative feature set to capture the individuality of each fingerprint and then does some strategies to determine the fingerprint class.

2.1 Fingerprint Classification

The first phase of is of fingerprint image classification. Most of the classification algorithms are classifying fingerprint image in five classes; Arch, Left Loop, Right Loop and Whorl. Kai Cao, Liaojun Pang, Jimin Liang amd Jie Tian [1] presented a hierarchical classifier which estimates the orientation of fingerprint using root filtering. Diffusion model is used to regularize the orientation to make classification rotation invariant. The classification is performed in five stages based on the singular point detection. In the first stage, arch is distinguished using complex filter responses. The second stage distinguishes whorl by using core point and ridge line flow classifier. The third stage identifies arch and whorl by k-NN classifier by using orientation fields and complex responses. Ridge line flow classifies loop arch. SVM is used for final classification.

Nannevan Noord and EricPostma [4] proposed the use of conventional neural networks to make image classification scale-invariant. The combination of scale-variant and scale-invariant features are used to attempt the image classification using task-relevant characteristics at multiple scales. Significant improvement in image recognition is stated due to the classification phase prior to recognition.

A fingerprint classification algorithm which uses Adaboost learning method is proposed by Manhua Liu [5]. Singularities are detected using complex filters responses at multiple scales.
and feature vector is constructed at each scale with relative position and direction of singularities. Adaboost learning method is applied on the decision tree to generate classifier for fingerprint classification. The experiments are carried out on NIST-4 database.

Shing Chyi Chua, Eng Kiong Wong and Alan Wee Chiat Tan proposed an algorithm for fingerprint classification by detecting the singular point via quantization [18]. A singular point is detected using a quantization approach on the orientation field of fingerprint image and core-delta points are located by the changes of the gray level around a 2 x 2 window. The unwanted singular points are removed with the application of edge-trace-cum-core-delta-pairing algorithm and merging-and-pruning algorithm. The experiments have been carried out on NIST-4 database for 5-class and 4-class classification.

Crease features are used for classification by observing crease features as strips in the fingerprint images [22]. Masking is used to remove noise from the extracted crease features. Minimum bounding box and convex hull is used to determine the size of every crease as it this feature is found robust to distortion and classification. The experiments are performed on Hong Kong PolyU High Resolution Fingerprint.

An approach is discussed by S. Govindaraju and G. P. Ramesh Kumar for retrieving medical images using robust features [3]. The method applies the SURF algorithm in the detection, description, extracting reference images and matching feature points in the image respectively. In the process of feature point matching, the false matching points are eliminated. Clusters are formed with the descriptors by applying BoF, centroids are formed and histogram is generated as an pre-requisite step for retrieval.

Local Binary Pattern (LBP) features are used by Guoying Zhao, Timo Ahonen, Jiri Mata, and Matti Pietikainen [14] for rotation invariant description of image and video description. The LBP operator is extended to use the circular neighborhood of different sizes. To make rotation invariant representation, bit pattern is circularly rotated to the minimum value. The experiments are carried out on Outex_TC_00012 database.

The magnitude component of LBP is utilized in leaf image classification by Anilkumar Muthevi [19] in which evaluate a value before generating bit pattern, which find the relativeness within a 3x3 neighborhood by using a value called threshold that is multiplied with the corresponding weights. The experiments are carried out on the various leaves databases to determine texture features using LBP approach.
Image classification using Gray Level Co-occurrence Matrix (GLCM) is proposed by A Suresh and K L Shanmuganathan [10]. GLCM is calculated from original texture image and the differences are calculated along the first singleton dimension of input texture image. Contrast, homogeneity, energy and correlation are calculated from GLCM. k-NN classifier is used for classification. System performance is evaluated by using Brodatz database and compared with the methods PSWT, TSWT, the Gabor transform and Linear Regression Model.

Another approach of texture extraction from image is proposed by P. Mohanaiah, P. Sathyanarayana and L. GuruKumar [9]. Features namely, Angular Second Moment, Correlation, Inverse Difference Moment and Entropy are computed. The experimental results are shown stating the texture features having high discrimination accuracy and requires less computation time. Hence GLCM is claimed having reduced image compression time in the process of converting RGB image to gray level image.

Ray-I Chang, Shu-Yu Lin, Jan-Ming Ho, Chi-Wen Fann and Yu-Chun Wang presented k-means and k-NN clustering algorithms for content based image retrieval system. Training of the system is performed by applying segmentation and grid generation, followed by k-means clustering and neighborhood table generation. The query image is going the same stages except k-NN clustering rather than k-means clustering. Future enhancements are also proposed for improved grid module to minimize the loss of information due to quantization.

Tran Son Hai, Computer Science Department and Nguyen Thanh Thuy have proposed the classifier k-NN for the classification of facial expressions [36]. Independent Component Analysis (ICA) is used to extract facial features. k-NN classifier uses the ratio features for classification along with Artificial Neural Networks. Basic seven universal facial expressions are the classes used for classification.

2.2 Fingerprint Retrieval

Fingerprint Retrieval is process of finding similarities among the query fingerprint image and that of from the fingerprint database. Using strong feature extraction methods which can represent the fingerprint images uniquely are used before matching. Distance matching strategies are used to find the similarities among the fingerprint images and n closest images are presented as a result [15][28].
K. C. Leung and C. H. Leung [11] have proposed the method for improving fingerprint retrieval by artificially expanding the set of training samples of fingerprints using spatial modelling technique. Bayes classification approach is used to classification and recognition of fingerprint images. The experiments have been carried out on FVC and NIST-4 databases.

Yashika Birdi and Er. Jagroop Kaur proposed a method based on wavelets in which first of all an input fingerprint image is decomposed up to three levels using DWT and then textural features are extracted [15]. Mean, standard deviation and energy computed to build feature vector. Similarity of fingerprint images is derived using Chi-square approach. Evaluation of the system is done through various parameters like Specification, Sensitivity, Positive Predictive Value, Negative Predictive Value, Recognition Rate and Accuracy.

Another wavelet based retrieval is discussed by Javier A. Montoya Zegarra, Neucimar J. Leite and Ricardo da Silva Torres [16]. Similar to the above approach, the fingerprint image is decomposed in different levels in wavelet domain and feature vector is built using mean and standard deviation. Different wavelets used in their study include: Gabor wavelets, tree-structured wavelet decomposition using both orthogonal and bi-orthogonal filter banks, as well as the steerable wavelets. Square Chord Similarity measure is used for retrieval.

Among the features used for accurate retrieval, SURF is popular due to its fast feature extraction approach. Sukhmanjeet Kaur and Mr. Prince Verma proposed and integration of Artificial Neural Network (ANN) using SURF and SVM [28]. The approach applies SURF for the detection description of the features. During the feature matching phase, false matching points are eliminated. The features built with SURF is applied to SVM and ANN for further classification.

SURF has been presented as a novel scale and rotational invariant detector and descriptor by Herbert Bay, Andreas Ess, Tinne Tuytelaars, Luc Van Goola [33]. For image convolution stages, the image is converted in Integral Image which makes the computations for the summation of any rectangular box faster than any other feature extraction approaches. SURF uses Hessian matrix-based measures for the detectors and detectors. SURF is applied for the camera calibration for image registration and object recognition.

Nursabillilah Mohd Ali, Soon Wei Jun, Mohd Safrin Karis, Mariam Md Ghazaly and Mohd Shahrrieel Mohd Aras have presented an approach of classification of the object by extracting
SURF features and statistical classifier [37]. The recognition of the object is performed by extracting the SIFT features.

E.N. Mortensen, Hongli Deng and L. Shapiro proposed SIFT as a descriptor which can find matches between features with unique neighborhood along with the global context vector for detecting the matching points of multiple images of a scene [35]. The SIFT helps in the detailing of local descriptors which is enhance by augmenting with global context vector to minimize the mismatches when multiple local descriptors are similar. Experiments are performed on variety of scene images and compared matching accuracy between the SIFT with global context to that without.

Hiroharu Kato and Tatsuya Harada have presented the Bag of Features (BoF) to reconstruct images. BoF is used as a histogram histogram of quantized descriptors extracted densely on a regular grid at a single scale [34]. Large-scale image database is used to estimate the spatial arrangement of local descriptors. They proposed a heuristic method to optimize jigsaw puzzle problem with adjacency and global location costs. BoF are extracted from various image categories and demonstrated the reconstruction of original images.

Chih-Fong Tsai presented the use of BoF for image annotation. The proposed approach is to help users to search the images through keywords but eliminates the labeling of images manually [32]. As image annotation problem can be regarded as an image classification problem, BoF classifier is used to represent global features of images. The detection of region of interest is performed and local descriptors are computed. The descriptors are quantized to words to generate vocabulary. BoW features are constructed by finding the occurrence of each specific word in the image.

3. Objective and Scope of work

A fingerprint classification system must be able to analyze and recognize the class, i.e. Arch, Left loop, Right loop and Whorl of a fingerprint image. The system should also be able to recognize fingerprint images accurately without human intervention. One of the objectives of this work is to develop a method which recognizes the fingerprint class using the statistical features extracted from the fingerprint images. Another objective is to develop a method of uniquely representing the fingerprint image so that most relevant images are retrieved in the retrieval phase which contains the similar fingerprint image.

The major objectives of this research work are summarized as below:
To develop an algorithm for fingerprint features extraction to recognize fingerprint class. Scale and rotation invariant features are extracted and given to the classifiers for class identification. The algorithm is to be tested on NIST – 4 standard database which contains 8-bit gray scale fingerprint image pairs.

To develop an algorithm which extract robust features such that it speeds up the process of feature extraction for retrieval. The algorithm should represent the local interest points which makes reduction in the size of feature vector and still strongly represent the class of fingerprints uniquely. The algorithm is to be tested on NIST – 4 database.

To develop an algorithm which uses hybrid feature extraction technique to extract features such that the given fingerprint image can be matched with similar image class images with improved accuracy.

The scope of the work:

- The work is tested on two standard databases NIST – 4 and FVC. NIST – 4 contains image pairs while FVC databases contains eight images of fingerprints.
- The work is taking in account the acquisition methods of fingerprint images. The training and testing of the images is performed with the same databases.

4. Original contribution by the thesis

In this thesis, method of fingerprint image classification and retrieval system is suggested with variations and combinations of feature extraction, classification and retrieval techniques. Images from two different databases are used. One is NIST special database 4 (NIST-4), Fingerprint Verification Competition databases (FVC2000, FVC2002 and FVC2004) and the fingerprint images captured using optical sensor with the help of volunteers.

The main contributions of this thesis are summarized as follows:

- The performance of the classification method strongly depends on the accuracy of the features extracted. A hybrid feature extraction method is developed that uses the combinations of different feature extraction algorithms. The feature extraction algorithms using LBP and GLCM are used collectively to extract features from fingerprint images. The concatenated features are given to the Support Vector
Machine classifier for classification. K-nearest neighbor (k-NN) classifier is also used for the comparison of the classification results.

- BoF classifier which is popular for document classification is experimented with the fingerprint images to check the possible improvements in the accuracy level of classification. The Speed-Up Robust Feature (SURF) algorithm is used to extract the features to test BoF classifier along with the hybrid feature extraction method. Both the classification algorithms are evaluated on NIST-4 and captured fingerprint images databases.

- It is essential to extract the features which are scale and rotation invariant to retrieve fingerprint images with accuracy. In retrieval phase, Scale Invariant Feature Transform (SIFT) features and SURF are used collectively to extract features from the fingerprint images of the same class. The concatenated features are extracted from these algorithms are given to BoF and other distance matching algorithms for indexing. The retrieval algorithms are evaluated on NIST-4, FVC and captured fingerprint image databases.

5. Methodology of research, results and comparisons

The work carried out in this research is focusing on basic three aspects of retrieval process; feature extraction, classification and retrieval. The other aspect of the system is the kind of input images. Standard image database NIST-4 contains the gray scale fingerprint image pairs taken by a specific acquisition source. FVC2000, FVC2002 and FVC2004 databases contains eight images of a fingerprint acquired from a specific source. The captured image using optical sensor with the help of volunteers contains four images for a fingerprint.

5.1 Fingerprint Classification Algorithm - 1

The work proposed for fingerprint classification in this algorithm has major two steps; feature extraction using LBP and GLCM and classification using Support Vector Machine and k-Nearest Neighbor classifiers.

5.1.1 Hybrid Feature Extraction using LBP and GLCM

5.1.1.1 Local Binary Pattern (LBP)

Feature extraction is the most important phase for classification and retrieval. The proposed work use of LBP features due to their strong local feature representation and computational
simplicity. LBP features describe changes of ridge patterns of fingerprint images of different classes and hence, would be efficient and effective for classification. The LBP operator labels the pixels of an image by thresholding a 3×3 neighborhood of each pixel with the centre value and considering results as a binary number, called as LBP Codes. After labelling a image with LBP operator, a histogram of the labelled image is found. This 256-bin histogram of LBP labels computed over a region contains information about the distribution of the local micro-patterns, such as edges of the ridges, ridge end-points and ridge bifurcations, so can be used as a texture descriptor to describe fingerprint image characteristics.

A LBP histogram computed over the whole face image encodes only the occurrences of the micro-patterns without any indications about their locations. The extracted feature histogram represents the local texture and global shape of fingerprint images.

5.1.1.2 Gray Level Co-occurrence Matrix (GLCM)

GLCM is a statistical method of examining texture that considers the spatial relationship of pixels. The GLCM functions create GLCM Matrix by characterizing the texture of an image by calculating how often pairs of pixel with specific values and in a specified spatial relationship occur in an image and then extract statistical measures from this matrix. Statistics can derived from this matrix provide information about the texture of an image. Few of them are; Entropy, Correlation, Energy and Homogeneity.

Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image. Correlation measures the dependency of grey levels of specified neighboring pixel pairs. Energy provides the sum of squared elements in the GLCM. It gives high value when image has very good homogeneity, i.e. when pixels are very similar. Homogeneity measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal.

The features from LBP and GLCM concatenated to obtain a single vector that is given to the classifier.

5.1.2 Classification

5.1.2.1 Classification using kNN Classifier

k-Nearest Neighbor classifies data sets based on their similarity with neighbors where ‘k’ stands for number of data set items that are considered for the classification. kNN makes predictions for a new instance(x) by searching through the entire training set for k most
similar instances (neighbors). To determine the similarity, a distance measure is used. For real valued input variables, Euclidian distance is used.

5.1.2.2 Classification using SVM Classifier

Support Vector Machine (SVM) is one of the known algorithms for pattern and image classification. SVM is designed to separate of the training images of different classes in feature space. It builds the optimal separating hyper planes based on a kernel function. All images of which feature vector lies on one side of the hyper plane are belong to one class.

5.2 Fingerprint Classification Algorithm – 2

The work proposed for fingerprint classification in this algorithm has major two steps; feature extraction using Speed Up Robust Features (SURF) and classification using BoF.

5.2.1 Feature Extraction using SURF

Feature extraction algorithm using SURF selects the interest points from the images at different scales using Hessian Matrix which can represent the texture of the image uniquely. In the initial step, the input image is represented as an Integral Image which minimizes the cost of calculating sum of intensity values of a rectangular region. With the neighborhood of every interest points, then it builds the feature vector which is distinctive and robust to noise and geometric deformations. To make features invariant to rotation, Haar wavelet responses are calculated within the circular neighborhood abound the interest point.

5.2.2 Classification using BoF

A BoF method is one that represents fingerprint images as orderless collections of local features. In the first step, from the features extracted by SURF technique, it clusters them into the pair of image and set of features contained in that image, to build a visual vocabulary. Then it records the count of each clusters appear in the image to create a normalized histogram representing cluster vector, which is known as BoF. Then it uses Nearest Neighbor method it assigns the cluster to the fingerprint image to declare the class.

5.3 Fingerprint Retrieval Algorithm

After declaring the class of fingerprint image, the retrieval of similar fingerprint images is performed within the class declared.
5.3.1 Hybrid Feature Extraction using SURF and SIFT

In the first step of SIFT feature extraction, algorithm starts with the scale-space extrema detection in which it identify the potential interest points by difference of Gaussian function (DoG). Then it determines the location and scale of interest point by detecting local maxima and minima of DoG. Interest point orientation can be calculated by orientation of histogram of local gradients. In the final stage, the local image gradients are measured at the selected scale in the region around interest point and transformed into scale-invariant coordinates relative to local features and feature vector is generated.

The features from SIFT and SURF concatenated to obtain a single vector that is given to the retrieval algorithm.

5.3.2 Retrieval using BoF

As explained earlier, BoF generate the clusters of the hybrid features generated in the previous step and tries to find the existence of feature cluster in the fingerprint image. Then it ranks each image based on its distance from the given fingerprint image, calculated based on Nearest Neighbor strategy. The rank results are ordered and the nearest \( n \) images whose distance shows the nearest images are displayed.

6. Achievements with respect to objectives

The objective of this work was to devise a method for accurate fingerprint image classification which minimizes the comparisons at retrieval stage. The retrieval method is expected to be accurate and speedy.

Different methods are proposed to achieve the stated objective. The feature extraction methods discussed in algorithm 1 are utilizing the advantages of both the methods LBP and GLCM to improve the classification rate. The SURF method, discussed in algorithm 2, speeds up the feature extraction process and hence improves the system response time. The classification is performed on standard databases as well as manually captured images.

The retrieval method proposed for fingerprint retrieval was carried out by utilizing the scale and rotation invariant features SIFT and SURF. Feature extraction is fast due to the SURF characteristics. Retrieval results are showing significant improvement using standard as well as manually captured image databases.
7. Conclusion

The feature extraction methods used for classification of fingerprint images are evaluated by generating confusion matrices by all combinations of four feature extraction methods (LBP, GLCM, Hybrid and SURF) and three classification methods (SVM, kNN and BoF). The experiments are performed on NIST-4 fingerprint image database. The experiment results are cross-validated using k-fold model. The results shown significant improvement when Hybrid and SURF methods used with BoF classifier.

Further, the fingerprint image retrieval is performed by using Hybrid feature extraction method and BoF for retrieval. The experiments are carried out on NIST-4 fingerprint image database and FVC databases by the combinations of three feature extraction methods (SIRF, SIFT and Hybrid) with BoF. The performance of the system is evaluated based on the performance measures precision and recall. Due to limited number of images of single fingerprint images, recall gives better evaluation analysis than precision. The results of Hybrid feature extraction method with BoF shows improvement in retrieval rate.
8. List of publications


9. References


Based on Visual Words Integration of SIFT and SURF”, Research Article, PLOS one, June 2016.


