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RESEARCH ARTICLE – PHYSICS

Enhance Fingerprint Images Classification Using Gabor filter and Minute Features Extraction

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Abstract

This research addresses the challenges associated with fingerprint image distortion in forensic science, as these distortions are a major obstacle that affects the accuracy and quality of matching methods. To achieve reliable identification, fingerprint scans must be of high quality. The paper used the Gabor filter to improve image quality and facilitate the visibility of small details. In addition, a study was conducted to compare the success of two new fingerprint classification methods. The first method relied on termination features using the Fuzzy C-means clustering approach, and two experiments were conducted: In the first experiment, termination features were adopted during the clustering process. In the second experiment, bifurcation features were adopted. The results showed that the second experiment performed better in achieving a higher classification accuracy level. Therefore, this research contributes to improving the effectiveness of automated fingerprint analysis tools used in crime scenes.

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1. Introduction

A popular biometric technique utilized in many forensic sciences, criminal investigations, commercial and civil identity systems is fingerprint identification. The input fingerprint images have a major impact on how well fingerprint image matching technology work [1]. Acquiring high-quality images is essential, however because of the user's physical state or the surroundings, a significant percentage of images are frequently of inferior quality [2]. Low-quality images have two drawbacks: they may create a lot of false details and miss a lot of the genuine aspects. Therefore, an image enhancement technique needs to be applied in order to increase the efficiency of the fine-detail extraction procedure [3].

Yusharyahya et.al (2014) assessed the efficacy of image enhancement by a comparative analysis of three distinct algorithms: power transformation in the frequency domain, spatial domain smoothing, and Gabor filter-based contextual filtering[4]. Kaggwa et.al (2016) employed a Gabor filter-based methodology, marking the first instance of a multi-registration based fingerprint identification system being implemented. Using the fingerprint datasets FVC 2000-DB2-A and FVC 2006-DB2-A, a spectral detail-based approach and a Gabor filter-based multi-fingerprint identification method were compare[5]. In 2016, Wang and et.al proposed an improved fingerprint recognition algorithm based on deep learning and convolution neural network (CNN) [6]
Palash Kumar Bose et.al (2017) their research aims to improve the accuracy and effectiveness of fingerprint identification techniques by addressing the challenges associated with distortion of fingerprint images. By applying advanced methods to enhance image quality and improve the extraction of fine details, this contributes to enhancing the reliability and performance of automated fingerprint analysis tools used in forensic investigations [7]. In 2019, Sharmila and et.al utilized multimodal biometric photos as input, extracting parameters including size, shape, texture, and edge. An algorithm for feature extraction, such the Gabor filter, is used to do this. It included information on multimodal biometrics, including its functions and the impact of the Gabor filter on these types of photos[8]. Marina González M. Sc et.al (2020) their research aims to provide a systematic review of the most recent studies conducted over the past decade on analytical methods for fingerprint analysis, with a focus on their chemical and biological components. The research seeks to clarify the analytical tools and techniques used, such as mass spectrometry, spectroscopy and other innovative methods, and summarize them in a specific table highlighting the main analytical criteria[9]. In order to ascertain personal identity in 2021, Basheer and et.al employ a fuzzy logic-based technique.

Approximately 220 subjects and temporal factors are considered to close the gap with current approaches. There were three methods employed: Fuzzy Ensemble Subspace Discriminant (FESD), Fine KNN (FKNN), and Fine Gaussian SVM (FSVM)[10].
In 2022, Ibrahim made a comparison between the different Roberts and Canny edge detection filters to determine which edge filters achieve better results, which in turn reflects the best pattern in the fabric. These filters are Laplace and Gabor [11] Al thabhawee et al., (2022) by proposing a highly efficient matching model for fingerprint recognition that leverages a deep learning-based convolutional neural network (CNN or ConvNet). The proposed convolutional neural network (CNN) consists of fifteen layers and is divided into two independent stages. The first stage is the preparatory stage, which involves collecting fingerprint images and then performing enlargement and pre-processing operations. The next step is to extract the unique features and then perform the matching process [12]. In 2023, Xinhua Lv conducted research on the use of the fingerprint image fuzzy edge detection algorithm in forensics with the goal of raising the field's standard and increasing the rate at which physical evidence is extracted. By merging the algorithms for images edge detection and fingerprint identification, the forensic technology system has been enhanced and refined. To guarantee that the investigation would be feasible, the nebulous hypothesis was introduced. Since hackers and criminals frequently change fingerprints to make phony fingerprints [13]. Hameed et.al. proposed an effective approach in 2023 for classifying fingerprint images as either original or altered. Our suggested approach made use of the most efficient texture characteristics and classifiers to increase the accuracy of fingerprint categorization. Discriminant analysis (DCA) and Gaussian discriminant analysis (GDA) are used as classifiers[14]. This research aims to improve the accuracy and effectiveness of fingerprint matching in forensic science by addressing the challenges of fingerprint image distortion. This includes using a Gabo filter to improve image quality and make it easier to see fine details. The study also wants to see how well two new fingerprint classification methods work, one that uses Fuzzy-C-Min clustering operators to focus on end features and the other on branch features. The overall goal of the research is to enhance the overall performance of automated fingerprint analysis tools used in crime scenes by increasing the accuracy and reliability of identification.

2. Fingerprint and its features

Fingerprint recognition is a biometric system used to identify individuals based on the unique characteristics of each person's fingerprint. These characteristics are constant and unchangeable throughout a person's life, making fingerprints a reliable and accurate standard for identification. Fingerprints consist of patterns and shapes known as ridges and valleys, with black lines representing ridges and white lines representing valleys [15].
System Stages: Fingerprint recognition consists of three main processes:
1. Acquisition: Digital images of fingerprints are collected using sensors.
2. Feature Extraction: Fine details such as terminations and bifurcations are extracted.
3. Matching: The extracted features are used to compare the user's fingerprint with stored data.
System Optimization Using Fuzzy-C-Mean Algorithm To address environmental challenges and changes in skin quality, fingerprint images were divided into three groups, as shown in Figure (1):
Group 0 (Natural): Does not contain dry or oily features.
Group 1 (dry): contains broken lines and rough areas.
Group 2 (oily): shows clear moisture in the depressions [16].

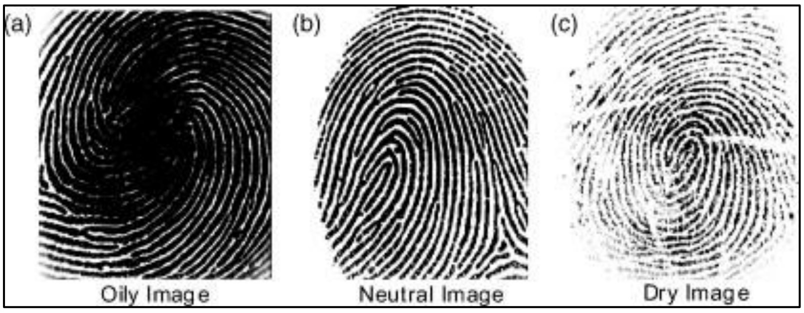

Figure (1) The type of fingerprints [7]

The role of physical properties of the fingerprint The physical properties of the skin greatly affect the quality of the captured images: dryness leads to broken lines and the appearance of many white dots. Humidity (oiliness) makes valleys appear darker, which can lead to noise in the images [17].

To improve the quality of the acquired images, pre-processing techniques such as standard filtering are used to remove noise and restore fine details. The quality of the image is evaluated based on the clarity of the boundaries between the highs and lows and the consistency of the distances between them [18].

Within automatic recognition systems, the focus is on two main types of fine details:

1. Terminations: the points where the highs end abruptly.
2. Bifurcations: the points where the highs begin to branch.

Figure (2) shows examples of these fine details, where the details are restored after filtering to improve the accuracy of recognition [19].

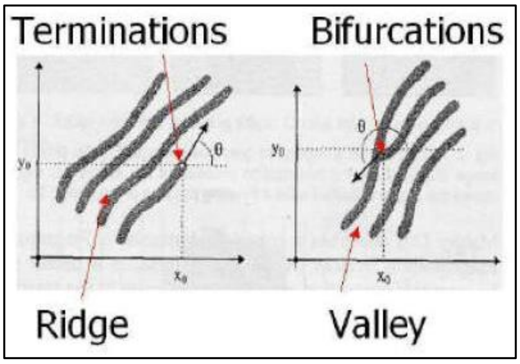

Figure (2) The fine detail of termination and branching [20]

The main objective of this system is to achieve accuracy and reliability in identifying individuals, through:

1. Providing a secure means of identification: Using the unique and stable characteristics of fingerprints ensures accurate discrimination between individuals, which enhances security in various fields.
2. Addressing environmental challenges: Improving the quality of captured images and dealing with problems associated with skin quality changes and environmental factors such as humidity and dryness.
3. Developing biometric systems: Improving the performance of systems using algorithms such as Fuzzy-C-Mean to reduce processing time and increase efficiency in image processing and segmentation.
4. Enhancing practical applications: Using the system in a wide range of fields such as security, surveillance, and personal identity verification.
5. Achieving efficiency in matching: Incorporating techniques such as extracting fine features (branches and ends) to increase the accuracy of the match [21].

2.1. Gabor Feature Extraction

The fingerprint image's distinctive features include its circular form and the recurring parallel ridges and valleys. The Gabor filter is capable of accurately detecting the optimal resolution for both high-frequency and low-frequency noise, as well as determining the frequency and direction of the data within the given field. The Gabor filter effectively eliminates noise while preserving the authentic ridge and valley patterns. As a result, these filters are effective in extracting fundamental information from images [19].

$$h(x, y, \varphi, f) = exp\left\{-\frac{1}{2}\left(\frac{\varphi_x^2}{\delta_x^2} + \frac{\varphi_y^2}{\delta_y^2}\right\} \times \cos(2\pi f \varphi_x) \ldots (1)$$

$$\varphi_x = xcos\varphi_x + ysin\varphi_x \ldots (2)$$

$$\varphi_y = -ysin\varphi_y + xcos\varphi_y \ldots (3)$$

Where $h(x, y, \varphi, f)$ is Gabor filter in the spatial domain, φ is Gabor filter orientation, f is sinusoidal of plane wave frequency, The Gaussian envelope's space constants along the x and y axes are denoted by δx and δy.
As fallows , the enhanced image EL(i, j) of the approximation sub-image is calculated [22]:

$$EL(i,j) = \sum_{u=-\frac{w_g}{2}}^{\frac{w_g}{2}} \sum_{V=-\frac{w_g}{2}}^{\frac{w_g}{2}} h(u,V,\hat{\varphi}\,(i,j),f)L(i-u,j-v) \ldots (4)$$

2.1.2 Fuzzy Logic

A type of logic that is applied in various expert systems and applications involving artificial intelligence. The Azerbaijani scientist Lutfi Z of the University of California devised this logic in 1661 with the intention of using it as a more efficient means of processing data. However, it wasn't until 1670 that he employed logic to support his thesis that it was given notice. The first usage of fuzzy logic was in the organization of a steam engine. From then, its uses grew until the creation of the Fuzzy Logic Chip, which was utilized in several goods, including cameras [23]. The fuzzy logic theory was developed by scientists for a variety of reasons.

The urge to design or program systems that can deal with erroneous information in the same manner that people can arose with the invention of computers and software. However, this presented a difficulty because computers can only deal with precise and accurate data. Fuzzy logic theory is one of the theories that may be used to create expert systems, or artificial intelligence, which is what this tendency has led to systems [24]. In its broadest definition, fuzzy logic is a logical framework for reasoning under uncertain circumstances that is built upon an extension of conventional two-valued logic. It is, strictly speaking, ideas and methods based on fuzzy sets that is, collections devoid of clear categories.

This reasoning offers a simple means of expressing and portraying the human experience. In addition, it offers workable answers to issues encountered in everyday life, which are also more affordable and efficient than those offered by other methods [25].

2.1.3 Traditional set and fuzzy set

Classic or traditional group an element can either belong to the group or not belong to it at all. Let us, for example, consider the set A and the set U if we define the function μ_A which gives Each element in group U has its degree of belonging to group A, by giving it the number 1 in the form of the element's belonging to the group, Aμ_A (x)=1 If the element of the set U, that is, the element x, belongs to the set A. If the element x does not belong to the function A, then the function μ_A gives it Number 0 μ_A (x)=1 Therefore, the function μ_A (x) can be expressed as follows:

μ_A (x): → {0,1} (x)

(x)→ μ_A (x) … (5)

The function can give results between 2 and 2, unlike the situation in classical logic.

The function returns only the number 2 or the number zeroYour paper must be in ONE-column format [26].

3. Results, Discussions and Future Work:

In this study, the FVC2000 DB1-B fingerprint image dataset was utilized to evaluate the proposed identification system. The dataset is characterized by the following specifications[27]:

- Impression kind: Normal.

- Image format: TIFF, 500dpi, 640x480 px.

- Documentation: Included within FVC2000 datasets.

- Enrollment process: Un-moderated.

- Sensor used: Optical, 500dpi, Secure Desktop Scanner by KeyTronic.

It is worth noting that the dataset includes 10 individuals, with each individual contributing 8 fingerprint images. In the initial stage, the images were loaded from the training folder, as depicted in Figure (3).[28]

Figure (3): Training samples from top to bottom: each row corresponds to 8 fingerprint images of person.

Stage 2: It involves enhancing each input fingerprint image using a Gabor filter as shown in figure (4).

Figure (4): An illustration of enhanced images from top to bottom: each row corresponds to 16 images (the original image and enhanced image) of person.

Stage 3: feature extraction: the minutiae features from each fingerprint image are extracted, including:

- **<u>Terminations features</u>**: include location of the minutiae point (LocX, LocY), and "theta", the angle of the ridge. Afterward, we have saved the extracted feature in.txt file to use later in clustering process. These features are variant for each fingerprint image.
- **<u>Bifurcations features:</u>** These are points where one ridge gets splits into two --> associated feature includes location of the minutiae point (LocX, LocY), and "theta1", "theta2", "theta3", the three angles of the ridges. These features are saved in separated .txt file to use later in clustering process. These features are variant for each fingerprint image.

Stage **4:** performing Fuzzy-c-mean clustering algorithm in term of unsupervised clustering to classify the training images into three main groups as: **cluster 0 (Normal), cluster 1 (Dry), and cluster 2 (oily) samples.**

<u>Experiments of clustering- Experiment 1</u>

- In this exterminate, the **Terminations features** are adopted for attending the clustering process.
- The parameters adopted in the fuzzy-c-mean clustering are: (Termfall, c=3, m=2, error=0.005, maxiter=1000),

where Termfall is 2D array consists of data points of Terminations features for 10 input images, no. of these features are 3357 data points, and each data point corresponds to minutiae end points structured as: (Location-X, Location-Y, theta (angle of ridge rotation). While C is the desired number of clusters (Normal, Dry, oily).

m, is Array exponentiation applied to the membership function u_old at each iteration, where U_new = u_old ** m.

error: is stopping criterion; stop early if the norm of (u[p] - u[p-1]) < error.

maxiter: is the maximum number of iterations allowed.

The results of this experiment represented by the figure (5).

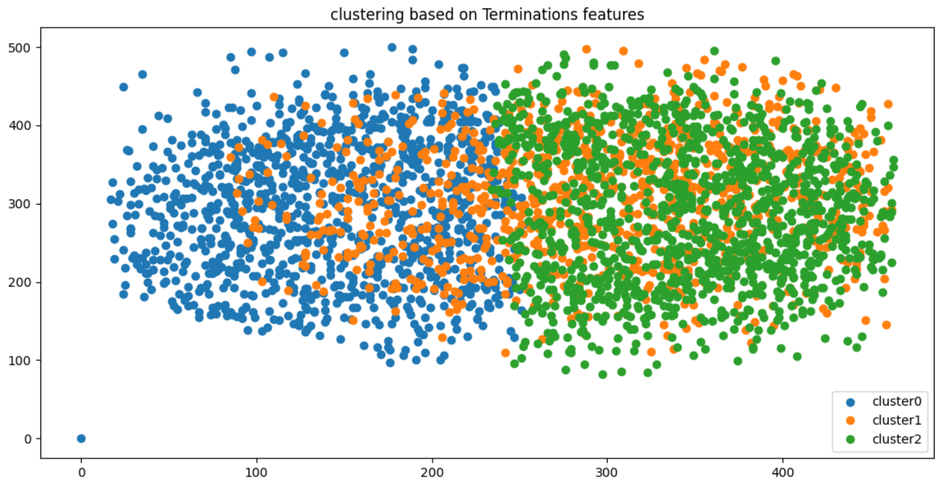

Figure (5): clustering of training samples based on Terminations features with Maximum iteration =1000

- Both cluster 0 and cluster 2 are separated well, while cluster 1 has poor separation and distribution, which overlapped between cluster 0 and cluster 2, figure (6).

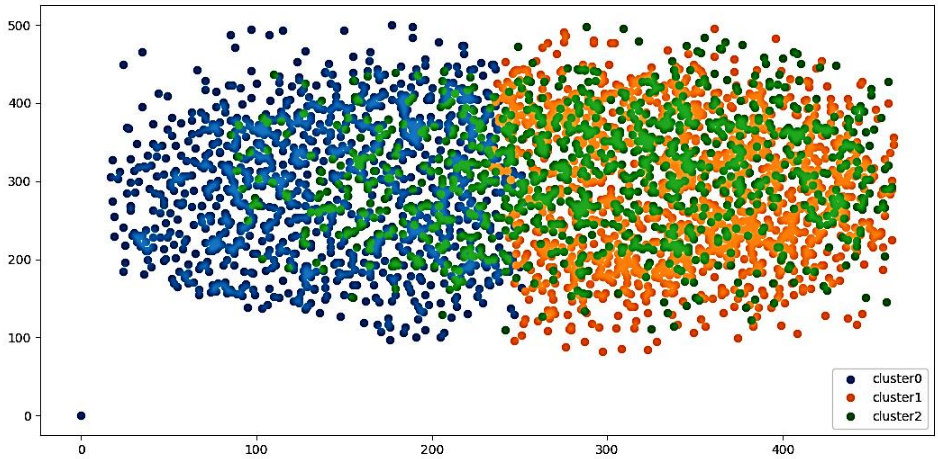

Figure (6): clustering of training samples based on Terminations features with Maximum iteration =2000

We have noticed that increasing the no. of iteration dose not effect on the outcomes of clustering process. Thus, we have fixed the maximum iteration number on 1000 iteration.

<u>Experiments of clustering- Experiment 2:</u>

- In this exterminate, the Bifurcations features are adopted for attending the clustering process as illustrated in the figure (8).
- The parameters adopted in the fuzzy-c-mean clustering are: (Bifrall, c=3, m=2, error=0.005, maxiter=1000),

where Bifrall is 2D array consists of data points of Bifurcations features for 80 input images, no. of these features are 2821 data points, and each data point corresponds to: where one ridge gets splits into two --> associated feature includes location of the minutiae point (LocX, LocY), and "theta1", "theta2", "theta3"

- The setting of the other parameters is similar to parameters setting in the experiment 1.
- As shown in the figure below, the three clusters have been separated well with higher clustering accuracy about 95% for each cluster.

The results of this experiment represented by the figure (7), result of the above two experiments, we found that the obtained results showed higher clustering accuracy based on the features of the ramifications. The work aims to design and implement a human identification system based on fingerprints using image enhancement techniques, fine-grained feature extraction, and clustering and classification methods to improve identification accuracy.

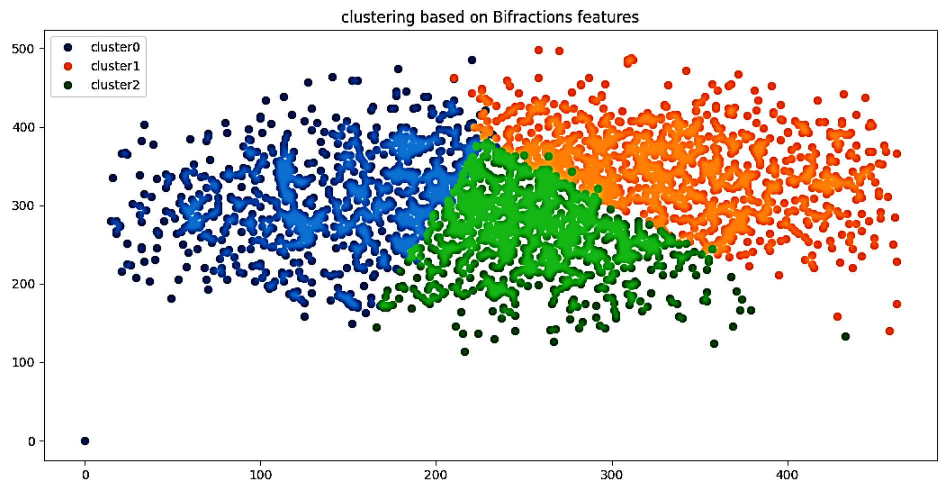

Figure (7): Visualization results of clustering the training samples based on Bifurcations features with Maximum iteration =1000

4. Conclusion

By employing Gabor filters for image enhancement and leveraging Fuzzy-C-Mean clustering algorithms, the study successfully demonstrated improvements in fingerprint recognition accuracy. The results revealed that clustering based on bifurcation features provided higher accuracy (95%) compared to termination features. These advancements contribute significantly to the development of efficient biometric systems, enhancing their application in fields such as security and forensic investigations.

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