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Fingerprint Recognition Based on Region of Interest (ROI) Extraction from Fingerprint Images

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ABSTRACT

Fingerprint authentication is one of the most developed and well-known biometrics because of its better accountability, better security and uniqueness. Common fingerprint recognition techniques which are based on complete fingerprint image do not perform well when fingerprint image is noisy or incomplete/partial. To overcome this drawback, we utilize part of the image which present in fingerprint image whether it's full or partial. Some portion of image which conveys meaningful information and consistent in every image refer as Region of Interest (ROI). We propose a mechanism which extracts ROI by removing inconsistent boundary region. Then resize image that called ROI of the image. Our proposed method performs effectively and accurately even though fingerprint image is noisy, incomplete/partial and not contains any reference point. By working on subset of image, the processing time is reduced. Thus, the fingerprint recognition becomes fast. Broad experiments over Fingerprint Verification Competition (FVC) database demonstrates the advantage of the proposed approach compared with different methods in literature.

Keywords: Region of Interest, RoI, Enhancement, Alignment, Fingerprint, Consistent region

INTRODUCTION

Biometrics is the scientific method of confirming or determining an individual's identity by analyzing physiological characteristics or behavioral patterns [7–9,25]. As a result, biometric recognition systems have been in use for a considerable time and continue to advance steadily, enhancing their effectiveness in authentication processes. Various types of biometric identification systems exist, such as fingerprint recognition, face recognition, iris recognition, voice recognition, and signature recognition [9–11]. Among these, fingerprint recognition is the most widely adopted due to the uniqueness and reliability of fingerprints [8–15]. Although the uniqueness of fingerprints is validated through manual analysis and their consistency is explained by the formation of friction ridges, fingerprint matching techniques [3–7] often depend on the entire fingerprint image. This reliance can lead to a higher False Accept Rate (FAR) [11,23,25] when the image is incomplete, noisy, or misaligned because of intra-class variations, ultimately reducing system accuracy. To improve accuracy, it is beneficial to focus on a specific, informative part of the image that is consistent across samples, known as the Region of Interest (ROI) [1–8]. Existing ROI extraction techniques typically rely on locating the core point, applying a fixed window around minutiae points [7–11], or using morphological operations. However, the first two methods require minutiae extraction, and the latter may fail when dealing with high-quality fingerprint patterns. In contrast, our approach functions effectively without needing to extract minutiae and performs well with both low- and high-quality fingerprint images [15].

Our proposed method extracts the Region of Interest (ROI) by adapting the image size based on whether the fingerprint is full or partial. The process begins with a preprocessing step [7–9] to enhance image clarity, followed by image alignment. Finally, the ROI is identified by eliminating the inconsistent boundary areas

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from the fingerprint image.

The primary contributions of our research are outlined below:

a) We introduce an innovative method for fingerprint image alignment, which leverages the angular difference between the left and right regions of the image.
b) Our technique is capable of identifying the Region of Interest (ROI) even in the absence of typical singular points such as the core and delta.
c) The proposed method consistently extracts accurate and comparable ROIs from both full and partial fingerprint images of the same individual.

The remainder of this paper is structured as follows: Section 2 presents a review of related work along with its limitations. Section 3 details the proposed methodology. Section 4 discusses the experimental setup and analyzes the results. Finally, Section 5 provides the conclusion of the study.

LITERATURE SURVEY

To accurately determine the core point, the process begins with detecting SIFT points [15], followed by applying reliability measures and ridge frequency criteria to reduce the number of potential candidates. To enhance core point detection accuracy, an appropriate mask is then applied. Once the core point is identified, the surrounding area is designated as the Region of Interest (ROI) [11–17]. The size of the ROI window is not fixed but dynamically adjusted based on the background extent, guided by the distribution of SIFT points. However, this method is prone to failure when the core point is absent or the fingerprint image is of low quality, resulting in a decline in system accuracy [28].

K. Sasirekha et al. [2] proposed a fingerprint identification method that combines invariant moments with minutiae features. Initially, the fingerprint image undergoes enhancement using the Short-Time Fourier Transform (STFT) [13–15], followed by morphological operations to refine the image. Minutiae points [24, 30] are then extracted and selected based on pseudo-minutiae pairs [2–5] from a thinned version of the image, with non-relevant minutiae filtered out using a boundary threshold relative to image dimensions. The Region of Interest (ROI) is determined based on the distribution of minutiae [22], and its size is defined as $m \times n$, where m and n represent the image's width and height, respectively. Once the ROI is selected, invariant moments [5–9, 24] are computed, which retain consistent properties under translation, rotation, and scaling. These invariant moment values, derived from the minutiae within the ROI, are used as fingerprint features, helping to safeguard the original image data and prevent information leakage while achieving a higher recognition rate. The final step involves computing a similarity score to determine fingerprint identity. This method is not restricted to images with a core point [20]; however, in the FVC2000 and FVC2002 databases, the Equal Error Rate (EER) increases when the ROI is reduced beyond a certain threshold.

M. Hanmandlu et al. [1] introduced a method for core point detection utilizing the Scale Invariant Feature Transform (SIFT). SIFT, commonly used in general-purpose recognition, identifies stable feature points [23], and each of these points is described using a feature descriptor to facilitate matching. The selected features are designed to be invariant to scale and rotation, ensuring robust recognition even under varying lighting conditions, image noise, and affine distortions [28–30].

M. Akram et al. [3] proposed a core point detection method that combines image segmentation [3–5] with orientation analysis. The process involves several key steps: segmentation [21], normalization, orientation field estimation, and ultimately, core point detection [20]. A modified gradient-based segmentation technique [19–21] is employed, which segments the image by analyzing gradient deviation values. This involves computing the gradient at each pixel, determining the mean gradient value, and then calculating the standard deviation to derive the gradient deviation.

Following segmentation, the orientation field is estimated by filtering out the background using coherence value calculations. The Region of Interest (ROI) is then defined based on the certainty of the background. Accurate core point detection is achieved by extracting the ROI and analyzing the orientation field. To precisely localize the core point, the Poincaré index method [4–8] is applied within the ROI. This approach performs effectively even under challenging conditions such as dry or oily fingerprint impressions. However, its accuracy diminishes when dealing with non-aligned or low-quality images [29].

D. Das et al. [5] proposed a fingerprint image segmentation technique utilizing morphological filtering and block-based analysis. Segmentation, in this context, refers to the process of isolating the foreground (actual

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fingerprint) from the background [19]. The method involves a two-phase block-based segmentation approach [21].
In the first phase, two distinct Regions of Interest (ROIs) are identified: (i) one through morphological filtering using the open-close operation, and (ii) the other by evaluating the coefficient of variation. These two ROIs are then combined to define the complete ROI [5–9].
The second phase refines this by applying a shrink-merge process based on the coefficient of variation, followed by another shrink-merge step using the average gray value of the blocks. The final segmented output is produced by applying both phases to the input fingerprint image.
However, some fingerprint images contain background areas with high-quality ridge-like patterns [27], making them particularly challenging to segment accurately [30].

Methodology

In this segment, we discuss about proposed approach. In our approach, we find out Region of Interest (ROI) from full or partial fingerprint image. Pre-processing technique apply on input image to get clean image when image is noisy and have poor quality due to dirt, grime and wound. Then alignment is performed on non-aligned image so make them vertical aligned. And finally, ROI is extracted from the output image obtain after alignment. Our proposed approach procedure is discussed in Fig. 1.

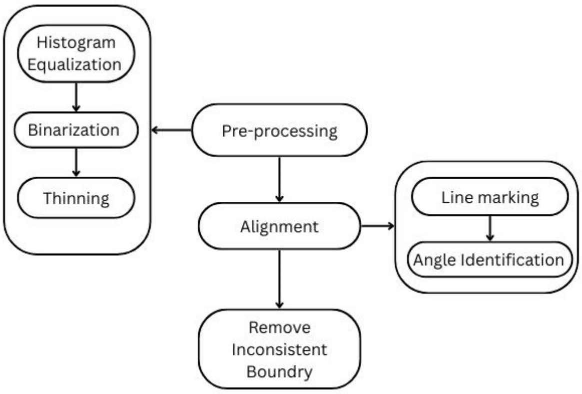

Fig 1. An Overview of Proposed Approach

1. Pre-processing

Pre-processing is a crucial step for improving the quality of fingerprint images [27]. Various pre-processing techniques—such as Histogram Equalization, binarization, and Thinning—are employed to prepare the image for further analysis, as outlined below:

I. Histogram Equalization

This method focuses on enhancing fingerprint images to improve clarity for subsequent processing tasks. Fingerprint enhancement aims to produce a more distinct and visually interpretable image. One common technique used is histogram equalization, which stretches the pixel intensity values across the full range to enhance visual detail. Typically, the histogram of a raw fingerprint image displays a bimodal distribution. After applying histogram equalization, the histogram spreads across the entire intensity range (0 to 255), resulting in improved visualization. This process is governed by the standard histogram equalization formula.

$$S_k = T(r_k) = \sum_{j=1}^{k} p_r\left(r_j\right) = \sum_{j=1}^{k} \frac{n_j}{n}$$

In this context, S_k represents the intensity value in the enhanced image that corresponds to r_k, the intensity value in the original fingerprint image. The function $p_r\left(r_j\right)$, where j=1,2,3,…,L, denotes the intensity levels of the input image, with L being the total number of possible intensity levels. Essentially, the values in a normalized histogram reflect the approximate probability of occurrence for each intensity level in the image. The figures below illustrate the difference between the histogram of a fingerprint image before (1) and after (2) applying histogram equalization, as implemented using the “histeq” function from MATLAB’s Image Processing Toolbox [31].

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***II.* Image Binarization**

The input fingerprint image is initially in grayscale format; therefore, it must first be converted into a binary image. This conversion is performed by applying a global threshold: pixel values above this threshold are set to 1, while all others are set to 0. To determine the optimal threshold value, Otsu's method is employed, which aims to minimize the intra-class variance between the foreground (white) and background (black) pixel intensities.

***III*. Thinnning**

The ridge thinning process is applied to eliminate redundant pixels and reduce ridge lines to a single-pixel width. This refinement is achieved using MATLAB's built-in thinning function, which streamlines the ridge structures for more precise analysis.

bwmorph (binary Image, "thin", Inf);

Then the thinned image is filtered by using the following three MATLAB‟s functions. This is used to remove some H breaks, isolated points and spikes.

bwmorph (binary Image, "hbreak", k);
bwmorph (binary Image, "clean', k);
bwmorph (binary Image, "spur', k);

The thinned fingerprint image contained single pixel width and discontinuities. The conditions for better thinning result:

a) Each ridge should be thinned to its centre pixel.
b) Noise and singular pixels should be removed.
c) No further removal of pixels should be possible after accomplish of thinning process [32].

2. Alignment

Fingerprint image alignment is carried out by drawing reference lines according to predefined criteria and calculating the angle between them. The alignment process is then executed based on the computed angle difference (see Fig. 2 for reference).

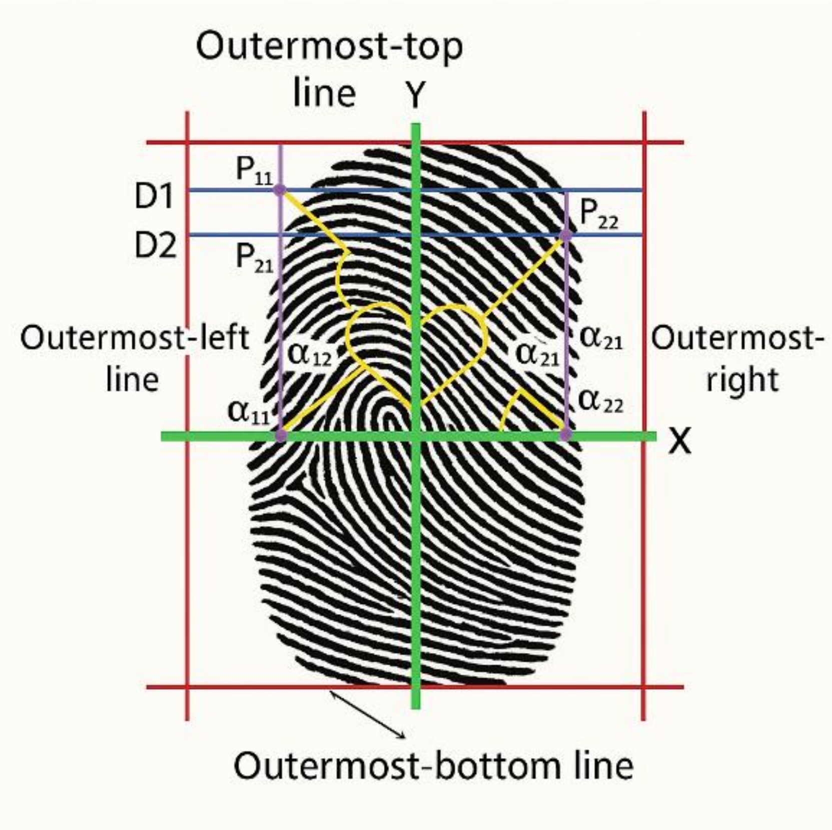

Fig. 2. Fingerprint Alignment

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I. Line marking and Angle Identification

To align the fingerprint image, an initial reference line is drawn and the angle between key features is calculated. Based on the identified angle, specific alignment procedures are then applied.

Line Marking: First, identify the highest point on the fingerprint image, where the image begins, and draw a horizontal line parallel to the x-axis passing through this point. This line is called the outermost-top line. Next, draw two additional horizontal lines, parallel to the outermost top line, at distances of D1 and D2 (as shown by the red line in Fig. 2). Keep in mind that D1 << H and D2 << H, where H represents the height of the input fingerprint image.

Angle Identification: Identify four intersection points: P11, P12, P21, and P22. To find P11 and P12, determine the intersection of the line at distance D1 with the image's bounding edge. For P21 and P22, locate the intersection of the line at distance D2 with the bounding edge of the image. The angles between the center point (C) and the points P11, P12, P21, and P22 are denoted as α11, α12, α21, and α22, respectively.

II. Alignment Procedure

To align the image, we use an alignment procedure that makes use of the values calculated in the previous section. The steps for the image alignment procedure are outlined below.

Case 1: $\alpha_{11} > \alpha_{12}$ and $\alpha_{21} > \alpha_{22}$

$$\boldsymbol{I_{rot}} = \frac{(\alpha_{11} - \alpha_{12}) + (\alpha_{21} - \alpha_{22})}{2}$$

Fingerprint image is rotated by $\boldsymbol{I_{rot}}$ in anti-clockwise direction.

Case 2: $\alpha_{12} > \alpha_{11}$ and $\alpha_{22} > \alpha_{21}$

$$\boldsymbol{I_{rot}} = \frac{(\alpha_{12} - \alpha_{11}) + (\alpha_{22} - \alpha_{21})}{2}$$

Fingerprint image is rotated by $\boldsymbol{I_{rot}}$ in clockwise direction.

Case 3: $\alpha_{11} > \alpha_{12}$ and $\alpha_{22} > \alpha_{21}$

$$\boldsymbol{I_{rot}} = \frac{(\alpha_{11} - \alpha_{12}) + (\alpha_{22} - \alpha_{21})}{2}$$

If $\alpha_{11} > \alpha_{22}$ then fingerprint image is rotated by $\boldsymbol{I_{rot}}$ in clockwise direction, otherwise anti- clockwise direction.

Case 4: $\alpha_{12} > \alpha_{11}$ and $\alpha_{21} > \alpha_{22}$

$$\boldsymbol{I_{rot}} = \frac{(\alpha_{12} - \alpha_{11}) + (\alpha_{21} - \alpha_{22})}{2}$$

If $\alpha_{12} > \alpha_{21}$ then Fingerprint image is rotated by $\boldsymbol{I_{rot}}$ in anti- clockwise direction, otherwise clockwise direction.

3. Region of Interest (ROI) Extraction

Several techniques have been proposed for extracting the region of interest (ROI) from fingerprint images [1–7]. However, methods that rely on selecting a reference point often perform poorly when the fingerprint image is noisy, misaligned, or partial. To address these challenges, we propose a method that determines the ROI based on the calculated height and width of the fingerprint image, whether it is full or partial. The proposed approach focuses on the central area of the image, which is typically present in both full and partial fingerprints. The ROI is obtained by eliminating irregular boundary edges from the image.

To extract the ROI, we first calculate the height and width of the fingerprint image based on the differences between the outermost lines. The maximum and minimum dimensions are denoted as H_high, W_high, H_low, and W_low. The height and width of the input fingerprint image are represented by H' and W', respectively. Once these values are determined, boundary edges are removed based on whether the fingerprint is full or partial, using different scenarios discussed below.

Scenario 1: Full Fingerprint

If the input is a full fingerprint image, the size is reduced by trimming T' pixels from the top and bottom, and T'' pixels from the left and right sides

$$H'' = H' - H_{low}$$
$$T' = \frac{H''}{2}$$
$$W'' = W' - W_{low}$$
$$T'' = \frac{W''}{2}$$

Scenario 2: Any one edge is Partial

If the input image is partial on any one edge, the image size cannot be reduced directly. Instead, a different approach is used to select the Region of Interest, as described below:

i. Top Edge is Partial: When the top edge of the image is partial, reduce the bottom side by T_b and trim the left and right sides in the same way as described in Scenario 1. Then, if the fingerprint's height exceeds the estimated height, remove the excess portion from the top.

$$H_b = H_{high} - H_{low}$$
$$T_b = \frac{H_b}{2}$$

ii. Bottom edge is Partial: If the bottom edge of the image is partial, trim the top side by T_t and reduce the left and right sides as in Scenario 1. Then, if the height of the fingerprint exceeds the estimated value, remove the excess portion from the bottom.

$$H_t = H_{high} - H_{low}$$
$$T_t = \frac{H_t}{2}$$

iii. Left edge is Partial: If the left side of the image is partial, reduce the right side by T_r and adjust the top and bottom as explained in Scenario 1. Then, if the width of the fingerprint exceeds the estimated width, remove the excess portion from the left.

$$W_r = W_{high} - W_{low}$$
$$T_r = \frac{H_r}{2}$$

iv. Right edge is Partial: If the right side of the image is partial, trim the left side by T_l and adjust the top and bottom as described in Scenario 1. Then, if the fingerprint's width exceeds the estimated width, remove the excess portion from the right side.

$$W_l = W_{high} - W_{low}$$
$$T_l = \frac{H_l}{2}$$

Scenario 3: Combination of two edges is partial

When two sides of the fingerprint image are partial, both the height and width must be adjusted. There are four potential scenarios for this, which are outlined below:

i. **Top and Left edge is Partial:** If the input image is partial on the top and left sides, the height and width should be adjusted following the procedures outlined in cases (i) and (iii) of Scenario 2..

ii. **Bottom and Left is Partial:** If the input image is partial on the bottom and left sides, the height and width should be modified according to the methods outlined in cases (ii) and (iii) of Scenario 2.

iii. **Top and Right is Partial:** If the input image is partial on the top and right sides, the height and width should be adjusted following the procedures outlined in cases (i) and (iv) of Scenario 2.

iv. **Bottom and Right Partial:** If the input image is partial on the bottom and right sides, the height and width should be reduced according to the methods outlined in cases (ii) and (iv) of Scenario 2.

Note that, this scenario doesn't contain cases like top and bottom partial or left and right partial.

Scenario 4: All edges are Partial, Top and Bottom Partial, Left and Right Partial

If the input fingerprint image exhibits partial edges on all sides top, bottom, left, and right it can be considered virtually a complete image. In such cases, the image size should be adjusted according to the procedure outlined in Scenario 1, as if it were a full fingerprint image.

EXPERIMENTAL RESULTS

In this section, we discuss about experimental setups and the experimental results to evaluate accuracy and the effectiveness of our proposed approach.

1. Database

Our method is applied to the FVC2002 dataset, which is divided into four sub-databases: DB1_B, DB2_B, DB3_B, and DB4. Each sub-database contains 80 fingerprint images from ten different users, with each user providing 8 images of the same fingerprint. The size of each fingerprint image is 388x374pixels.

2. Evaluation Setup

We conduct our various experiments with an Intel(R) Core(TM) i5-6500 CPU @ 3.20 GHz processor. We use MATLAB R2017a to implement our program using Windows 7 Operating System.

3. Comparison with Existing Work

Table 1 specifies the comparison of proposed approach with the previous works in terms of different mechanism and various observation of the system (refer Table 2).

Table 1
comparison with existing work

Work	Pre- Processing	Feature	ROI Extraction Technique	Remarks
M. Hanmandlu et al. [1]	• Enhancement based on short time Fourier	• Scale invariant feature transform (SIFT) to detect core point	ROI varied as per the extent of the background from the core point	When core point is missing and poor-quality fingerprint image this method fails
K. Sasirekha et al. [2]	• Short Time Fourier Transform (STFT) for enhancement	• Extract minutiae • Remove Pseudo feature points	ROI selected according to minutiae points and with fixed window size	EER value will increase when ROI is reduced to a certain value in databases
M. Akram et al. [3]	• Modified gradient based Segmentation • Fine Orientation Field Estimation	• Poincare Index method for core point detection	ROI is located as per core point and background certainty	Accuracy to extract optimal core point is decreased when non-aligned and low-quality image
R. Kaur et al. [4]	• Normalization • segmentation • Orientation • Ridge segmentation • smoothing • Thinning	• Minutiae Extraction • Minutiae post processing	ROI extracted using structuring element of morphology operation	After enhancement image contain less number of minutiae which not maintain uniqueness
D. Das et al. [5]	• Morphology Filtering	• Calculate coefficient of variation	ROI extracted by combining morphological filtering and coefficient of variation	Quite difficult to segment when high quality ridge like patterns in background

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Proposed Approach	• Binarization, Morphological Filtering, Image Enhancement	• Height and width calculation • Alignment of the image	Remove uncertain boundary region and extract ROI	• Efficiently extract ROI even if core point missing • ROI extraction not based on minutiae feature points • Work accurately with noisy and low quality fingerprint image

4. Experiments and Results

I. ROI Extraction from different images

We obtain different impressions of the same individual and extract the region of interest (ROI) from all the images. The extracted ROIs from these different impressions are similar, as illustrated in Fig. 3.

Fig 3. ROI Extraction from the different impression of identical person

II. Operation performed on Input Image

In this case, the input image is of low quality, with partial top and bottom edges, and misaligned. Therefore, we first enhance the image, then align it according to the procedure outlined in Section 3. Finally, we remove the inconsistent boundary regions as described in Scenario 2. The resulting image, with the extracted ROI, is shown in Fig. 4.

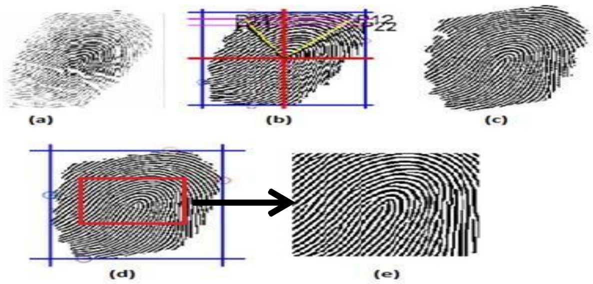

Fig 4. (a) Input image; (b) Enhanced image with marked points; (c) Aligned image; (d) Remove uncertain boundary region; (e) ROI

III. ROI Extraction without and with alignment

We conduct experiments on both aligned and non-aligned fingerprint images. For the non-aligned images, the extracted ROI includes some inconsistent regions (as indicated by the yellow mark in Fig. 5(b)) and exhibits varying orientations. However, after aligning the image, the ROI extraction focuses on the central area, which eliminates inconsistent regions and ensures that the extracted ROI is consistent, with the same orientation, as in other images of the same person.

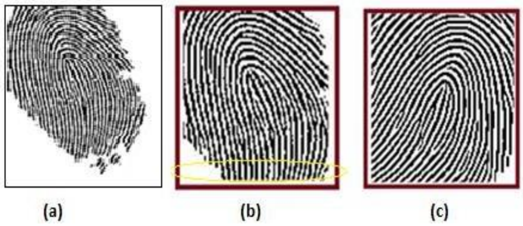

Fig 5. (a) Input image; (b) ROI from non-aligned image; (c) ROIfrom aligned image

5. Accuracy Table

Accuracy for fingerprint alignment and ROI extraction is discussed in Table 2.

Table -2 Accuracy Table

Work	Fingerprint Alignment	Work	ROI Extraction
Mazira et al. [23]	**81.62 %**	M. Hanmandlu et al. [1]	**95.25 %**
P. Jaganathanet al. [9]	**88.75 %**	M. Akram et al. [3]	**94.6 %**
Proposed Approach	**89.99 %**	Proposed Approach	**95.38 %**

CONCLUSION

To tackle the issue of ROI extraction based on a reference point, we propose a method that extracts the region of interest by resizing the image according to various cases for both full and partial/incomplete fingerprint images. The image is resized by removing inconsistent boundary areas from the fingerprint.

The proposed method extracts the ROI without compromising the image quality and consists of three main steps: Pre-processing, Alignment, and Region of Interest extraction. Some existing methods do not perform well on partial fingerprint images. Experiments conducted on the FVC2002 dataset show that our approach outperforms others, requiring less processing time to handle fingerprint image segments, thereby improving system efficiency. The experimental results demonstrate that our system performs accurately and efficiently across different scenarios.

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