SDM COLLEGE OF ENGINEERING AND TECHNOLOGY, Dharwad-580002

(An autonomous Institution affiliated to Visvesvaraya Technological University, Belagavi – 590018)

Department of Electronics and Communication Engineering

Report on Minor Project entitled

"MINUTIAE EXTRACTION METHODS: A COMPREHENSIVE COMPARISON"

Submitted by

Ms. SANGEETA . A– USN:2SD22EC079
Ms. SINDHU . K – USN:2SD22EC094
Ms. TEJASHWINI . K – USN:2SD22EC113
Ms. VAISHALI . R – USN:2SD22EC114

Students of 5th Semester

Under the guidance of

Prof. Reshma Nadaf

Department of ECE, SDMCET, Dharwad-580002

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Ms. Sangeeta . A
Ms. Sindhu . K
Ms. Tejashwini . K
Ms. Vaishali . R

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CHAPTER-1

1.1 INTRODUCTION:

Fingerprint recognition is a widely used biometric technology due to its uniqueness, permanence, and reliability. At the core of fingerprint recognition systems lies minutiae extraction, which involves identifying the ridge endings and bifurcations from a fingerprint image. These features are essential for accurate fingerprint matching and play a critical role in the overall performance of biometric systems.

Among the critical steps in these systems, minutiae extraction serves as the foundation for fingerprint feature matching. Minutiae, which are unique patterns of ridge endings and bifurcations, offer a highly distinctive representation of fingerprints. This project focuses on comparing the various minutiae extraction methods to understand their efficacy, efficiency, and real-world applicability.

This project aims to conduct a comprehensive comparison of various minutiae extraction methods, examining their techniques, strengths, weaknesses, and applicability in different scenarios. The study will cover traditional image processing-based methods as well as advanced machine learning and deep learning techniques. By evaluating their accuracy, computational efficiency, robustness to noise, and scalability, the project will provide valuable insights into selecting the most suitable methods for diverse real-world applications.

The ultimate goal is to provide a clear, detailed, and practical comparison that will aid researchers and developers in choosing the most effective minutiae extraction techniques for their specific needs.

1.2 MOTIVATION:

Minutiae extraction is the foundation of fingerprint recognition systems, playing a critical role in applications ranging from personal security to forensics. However, challenges such as noise, distortions, sensor variations, and low-quality images often hinder the effectiveness of extraction methods. Over the years, numerous techniques have been developed, including traditional image-processing algorithms, machine learning models, and hybrid approaches, each tailored to specific challenges. Despite this diversity, there is a lack of comprehensive evaluation to assess their performance across varied conditions. This project seeks to address this gap by systematically comparing these methods to identify the most reliable and efficient approaches. Such a comparison is essential for improving system reliability in high-stakes applications like law enforcement and financial security, optimizing performance in real-world scenarios, and providing clear benchmarks for developers and researchers. Additionally, by highlighting the strengths and weaknesses of current methods, the project aims to drive innovation, facilitate the adoption of hybrid solutions, and support the standardization of minutiae extraction techniques for next-generation biometric systems.

1.3 PROBLEM STATEMENT:

- Accurate fingerprint minutiae extraction is critical for reliable biometric authentication and forensic analysis.
- However , challenges such as noisy images , partial fingerprints and variability in ridge quality can compromise extraction accuracy.
- This study aims to compare different fingerprint minutiae extraction algorithms based on accuracy , execution time and number of minutiae points extracted from image.

1.4 OBJECTIVES:

- To extract Minutiae points from sample images from standard database.
- To analyze the computational complexity and execution time of each algorithms .
- Compare the accuracy of different fingerprint minutiae algorithms
- To determine the most efficient algorithm for fingerprint minutiae extraction.

CHAPTER -2

2.1 LITERATURE SURVEY:

Roli Bansal , Priti Sehgal and Punam Bedi (2011) "Minutiae Extraction from Fingerprint Images – A Review."

The paper "Minutiae Extraction from Fingerprint Images - A Review" discusses various methods for extracting minutiae (ridge endings and bifurcations), key features used in fingerprint recognition systems. These minutiae help identify individuals, but poor image quality, caused by noise, skin conditions, and inconsistent capture, complicates accurate extraction.

The review classifies extraction techniques into two categories: binarized and grayscale images. Binarized methods include thinning-based techniques, like the Crossing Number, and unthinned approaches such as chaincode processing and run-length encoding. Thinning simplifies ridges but introduces artifacts, requiring additional post-processing to eliminate false minutiae. Unthinned techniques avoid these issues by directly analyzing ridge patterns.

Grayscale methods bypass binarization and thinning, preserving image details and reducing spurious minutiae. These techniques include ridge-following, Gabor phase-based methods, and fuzzy logic approaches, all focused on maintaining the integrity of ridge structures for more accurate extraction.

The paper highlights the importance of preprocessing, such as image enhancement and normalization, to improve accuracy. Advanced methods like neural networks and morphological operations further refine minutiae detection.

Silas KivutiNjeru and Dr Robert Oboko(2016) "Comparative Analysis of Minutiae Based Fingerprint matching Algorithms."

The paper "Comparative Analysis of Minutiae-Based Fingerprint Matching Algorithms" by Silas Kivuti Njeru and Dr. Robert Oboko compares two fingerprint matching algorithms: one based on minutiae triangulation and another combining minutiae points with global orientation features. The research evaluates the performance of these algorithms in terms of speed, accuracy, and the number of features identified.

The study uses a dataset of 100 candidates, with four fingerprint images per individual. Results show that the minutiae triangulation-based algorithm (M-triplet) outperforms the minutiae and global orientation algorithm in terms of speed, with an average matching time of 38.32 milliseconds compared to 563.76 milliseconds for the latter. However, the minutiae and global orientation algorithm offers higher accuracy, with an average similarity score of 0.1424 compared to 0.0042 for the M-triplet algorithm**.**

The paper emphasizes the importance of selecting the right algorithm based on the application's requirements, considering both computational resources and the desired accuracy. The research suggests that for large-scale systems, factors like speed, memory usage, and accuracy should be carefully balanced, and proposes improvements such as parallel processing and better image enhancement techniques to optimize performance.

Sunny SUDIRO And Michel PAINDA VOINE(2007) " Simple Fingerprint Minutiae Extraction Algorithm using Crossing Number on Valley Structure."

The paper, "Fingerprint Image Enhancement and Minutiae Extraction," focuses on improving the reliability of fingerprint recognition systems through image enhancement and minutiae extraction. Fingerprints, a primary biometric for identification due to their uniqueness and stability over time, are often degraded by environmental factors or poor acquisition conditions. The study explores various algorithms for preprocessing and extracting minutiae points, key features in fingerprint patterns, to ensure accurate matching.
Three main approaches to fingerprint matching are discussed: correlation-based, minutiae-based, and pattern-based methods. The study implements the minutiae-based technique, targeting two principal features—ridge endings and bifurcations.
The process involves two key stages: minutiae extraction (image enhancement, segmentation, thinning, and marking) and minutiae matching (alignment and scoring). Enhancement techniques like histogram equalization, Fast Fourier Transform, and binarization are applied to improve image quality Segmentation.

Socheat . S and Wang .T . J (2020) "Fingerprint Enhancement , Minutiae Extraction and Matching Techniques."

The article, "Fingerprint Enhancement, Minutiae Extraction, and Matching Techniques," examines fingerprint technology as a critical tool in digital identification. It highlights the transition from traditional methods like IDs and passwords to biometrics, emphasizing fingerprints' uniqueness due to their ridges and valleys. The paper identifies challenges such as poor-quality images caused by dry or wet fingers, which hinder system accuracy.
The study introduces a three-step process: image enhancement using Gabor filters, minutiae extraction through binarization and thinning algorithms like Zhang-Suen, and minutiae-based fingerprint matching. Minutiae points, such as ridge endings and bifurcations, are extracted and compared with stored templates to verify identities.
Fingerprint technology has widespread applications, including law enforcement, access control, and personal devices. It is seen as more secure than passwords due to its non-replicable nature. The paper also discusses

biometric systems' evolution, emphasizing the need for continuous innovation to handle large-scale databases and improve recognition speed.

Manvjeet Kaur, Mukhwinder Singh and Akshaay Girdhar (2008) "Fingerprint Verification system using Minutiae Extraction techniques . "

The paper focuses on a fingerprint verification system based on minutiae extraction, a common method in fingerprint recognition. Fingerprint recognition relies on detecting minutiae—specific ridge features such as terminations and bifurcations. The system addresses key challenges like handling poor-quality impressions, image distortion, and false minutiae.

The proposed system involves three primary stages: preprocessing, minutiae extraction, and post-processing. In preprocessing, techniques like Histogram Equalization and Fourier Transform are used to enhance fingerprint images, followed by binarization and region segmentation using morphological operations. Thinning algorithms reduce ridges to a single-pixel width to facilitate minutiae extraction.

Minutiae extraction relies on detecting ridge endings and bifurcations using the Crossing Number (CN) method. An enhanced thinning algorithm ensures accuracy by eliminating erroneous pixels that might disrupt bifurcation detection. Post-processing focuses on removing false minutiae caused by image noise or imperfections.

The matching process involves aligning two fingerprint images, transforming minutiae to a unified coordinate system, and employing an elastic matching algorithm to identify corresponding features.

2.2 METHODOLOGY:

1.Dataset Collection

- Collect a dataset of fingerprint images from various sources, including public databases.
- Ensure the dataset includes a diverse range of fingerprint patterns, qualities, and sizes.

2.Preprocessing

- Enhance the quality of the fingerprint images using techniques such as histogram equalization,thinning, filtering, and binarization.
- Normalize the images to a standard size and resolution.

3.Minutiae Extraction Algorithms

- Implement and compare the performance of multiple minutiae extraction algorithms, such as:
    - Crossing Number (CN) algorithm
    - Zhang suen algorithm
    - Morphology Based algorithm
    - Chain Code Method algorithms

4.Performance Evaluation Metric

Evaluate the performance of each algorithm using metrics such as:

- Accuracy
- Efficiency
- Number o- f Minutiae points
- Ease of implementation

5.Result Analysis

Analyze and compare the results of each algorithm using Matlab software and visualizations.

- Identify the strengths and weaknesses of each algorithm and discuss their implications for fingerpint systems and identify most efficient algorithm for fingerprint minutiae extraction.

CHAPTER-3

3.1 BLOCK DIAGRAM:

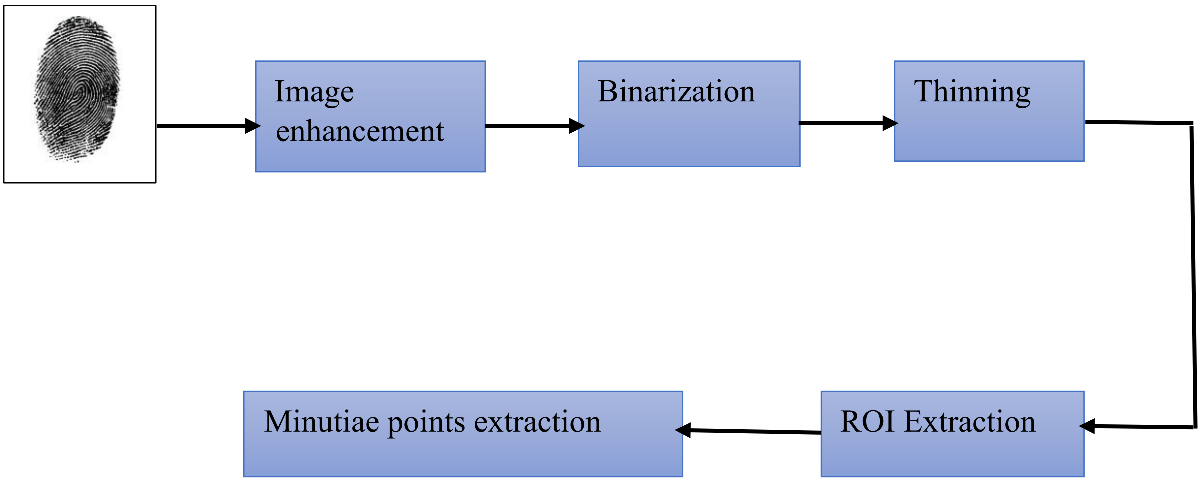

Fig1: Block digram

1. Fingerprint Image Acquisition

A fingerprint image is obtained using a scanner, sensor, or camera-based device.
It captures the ridge and valley patterns of the fingerprint that form the basisor further processing.

2. Image Enhancement

The raw fingerprint image often contains noise, blurriness, or incomplete ridge details.Enhancement techniques (e.g., histogram equalization, filtering) are applied to improve contrast and clarity of ridges and valleys.

3. Binarization

The enhanced image is converted into a binary format (black and white).

Ridges are represented as black pixels, and valleys (background) are represented as white pixels.

This simplifies the image for further analysis by reducing the complexity.

4. Thinning

The binary image undergoes a thinning operation to reduce ridge thickness to a single pixel width.

Thinning ensures that the skeleton of the ridge structure is extracted while preserving connectivity and shape.

This step is crucial for identifying minutiae points accurately.

5. Region of Interest (ROI) Extraction

Not all parts of the fingerprint image are useful; noise or incomplete areas around the edge are ignored.

The core region of the fingerprint (centre of ridge patterns) is extracted.

This helps focus on the most reliable area for minutiae detection.

6. Minutiae Points Extraction

Minutiae points are the unique features of a fingerprint, such as:

Ridge endings: Points where ridges terminate.

Bifurcations: Points where a ridge splits into two.

Algorithms analyze the thinned and ROI-extracted image to identify these minutiae points.

These points are crucial for fingerprint matching and identification systems

3.2 FLOWCHART:

1. ZHANG SUEN ALGORITHM

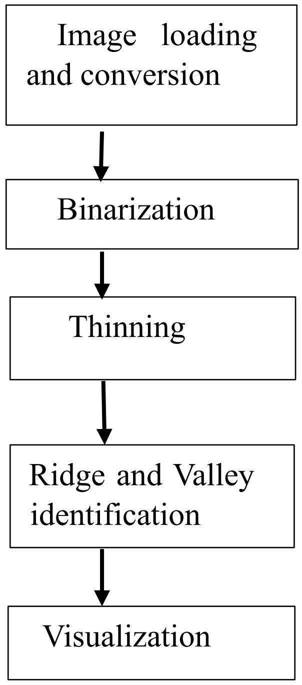

Fig 2: flow diagram of Zhang Suen Algorithm

- **Image Loading and Conversion :** Reads a fingerprint image and converts it to grayscale if necessary.
- **Binarization :** Applies Otsu's thresholding (graythresh) to convert the grayscale image into a binary image . **Purpose:** Segments the image into foreground (ridges) and background (valleys).
- **Thinning :** Applies Zhang-Suen thinning (bwmorph with 'thin') to reduce ridges to single-pixel width . **Purpose:** Simplifies ridge representation.
- **Ridge and Valley Identification Ridges:** Extracted from the thinned binary image . Valleys: Identified as the background areas that are not part of the white border.
- **Visualization :**

  Grayscale Image :Displays the original grayscale fingerprint .

  Binary Image: Shows the binarized version of the fingerprint .

  Ridges and Valleys : Overlays ridges in blue and valleys in red on the binary image.

2. CROSSING NUMBER ALGORITHM:

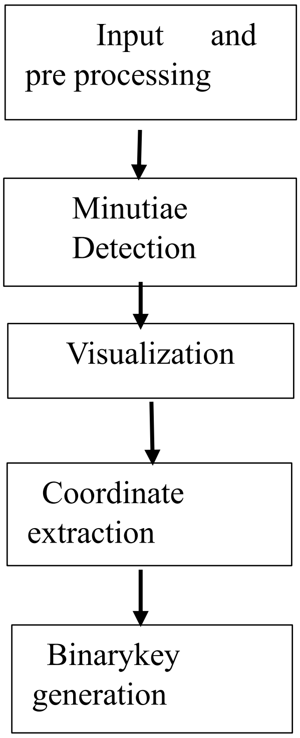

Fig 3: flow diagram of Crossing Number Algorithm

- **Input and Preprocessing :** Reads and binarizes the fingerprint image . Thins the binary image to a single-pixel ridge skeleton using bwmorph.
- **Minutiae Detection :** A 3×3 sliding window checks each ridge pixel
- Ridge Ending: Pixel with 2 ridge neighbors .
- Bifurcation: Pixel with 4 ridge neighbors.
- **Visualization :** Overlays red squares on ridge endings and blue squares on bifurcations.
- **Coordinate Extraction :** Stores ridge and bifurcation coordinates in MX (X-coordinates) and MY (Y-coordinates).
- **Binary Key Generation :** Converts MX and MY values into 7-bit binary strings . Concatenates these strings to form the final binary key for use in fingerprint-based biometric systems

3. CHAIN CODE METHOD ALGORITHM:

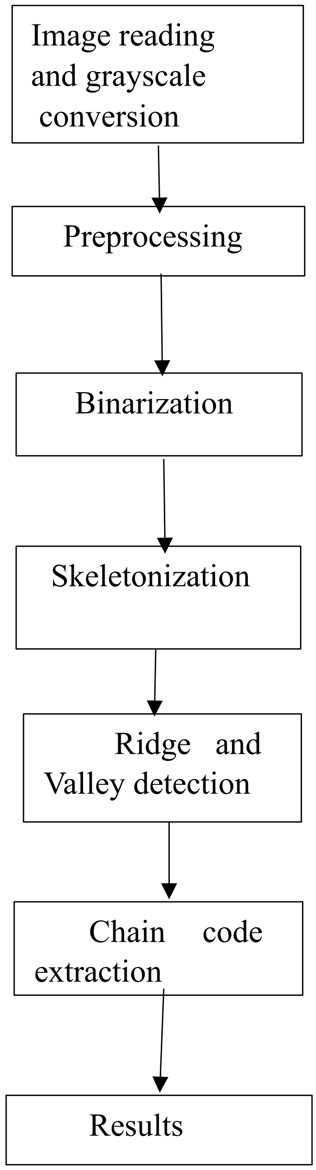

Fig 4 : flow diagram of Chain Code Algorithm

- **Image Reading and Grayscale Conversion :** Loads the fingerprint image and ensures it's grayscale.
- **Preprocessing :** Noise Reduction: Gaussian smoothing Contrast Enhancement: Adaptive histogram equalization .
- **Binarization :** Converts the grayscale image to a binary form, segmenting ridges and valleys.
- **Skeletonization :**Thins the binary image to single-pixel-width ridges using bwmorph.
- **Ridge and Valley Marking Marks:** Ridges: Blue (RGB = [0, 0, 255]).

Valleys: Red (RGB = [255, 0, 0]).

- **Chain Code Extraction :** Encodes each ridge's structure as a sequence of directions in an 8-connected grid . Traces unvisited ridge pixels and records their directions
- **Results :** Shows the processed images and outputs chain codes for detected ridges.

4.MORPHOLOGY BASED ALGORITHM:

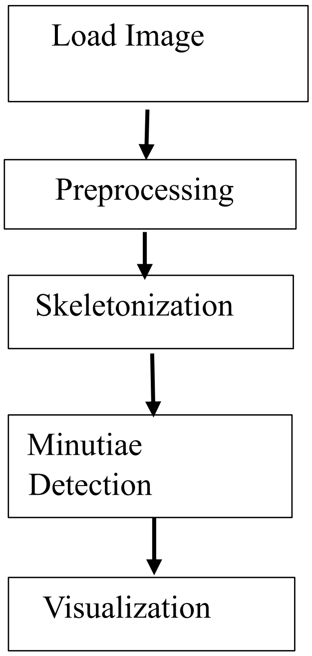

Fig 5: flow diagram of Morphology Based Algorithm

- **Load the Image:** Reads the fingerprint image from the specified path.
- **Preprocessing:** Converts the image to grayscale (if it's RGB).Binarizes the grayscale image to segment ridges (foreground) from valleys (background).
- **Skeletonization :** Uses morphological thinning (bwmorph) to reduce ridges to single-pixel width . Simplifies ridge structures for minutiae detection.
- **Minutiae Detection (Custom Function):**The function detect minutiae identifies:
- Ridge Endings: Points with only one connected neighbor in a 3x3 neighborhood.
- Bifurcations: Points with exactly three connected neighbors in the 3x3 neighborhood.
- Detection Logic : For every ridge pixel in the skeleton, examine its 3x3 neighborhood .
- Neighbor Count = 1: Ridge ending .
- Neighbor Count = 3: Bifurcation .
- Stores coordinates of these points in endings and bifurcations.
- **Visualization :** Displays the binary image and overlays detected minutiae : Red stars (r*): Ridge endings . Blue circles (bo): Bifurcations.

3.3 SOFTWARE:

Fig 6: Matlab

MATLAB, short for Matrix Laboratory, is a high-level programming language and interactive environment widely used in engineering, science, and mathematics. It excels in numerical computing, data analysis, and visualization, with a syntax that is intuitive for matrix and array operations. MATLAB is equipped with a vast set of built-in functions and toolboxes, making it a powerful tool for diverse applications, from signal processing to machine learning.

CHAPTER 4

4.1 RESULTS:

1. ZHANG SUEN ALGORITHM:

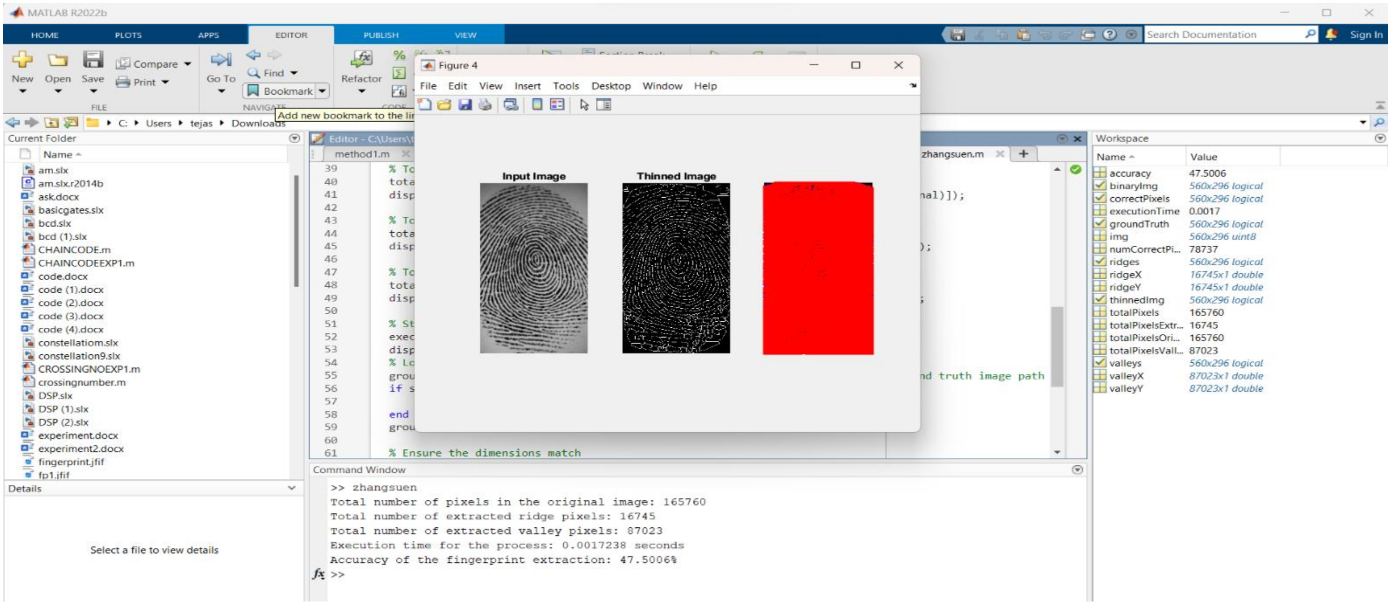

Fig 7: Output image

2.MOROPHOLOGY BASED ALGORITHM:

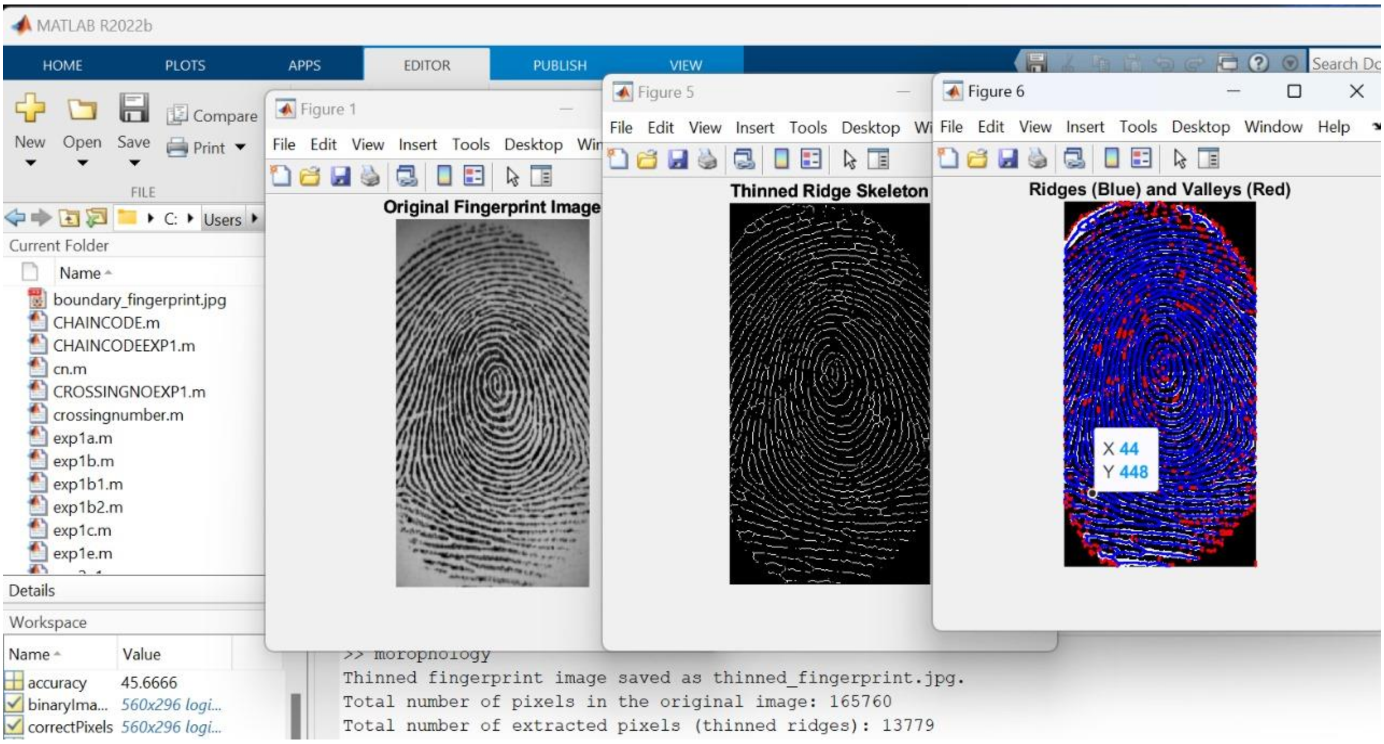

Fig 8: Output image

3.CHAIN CODEALGORITHM:

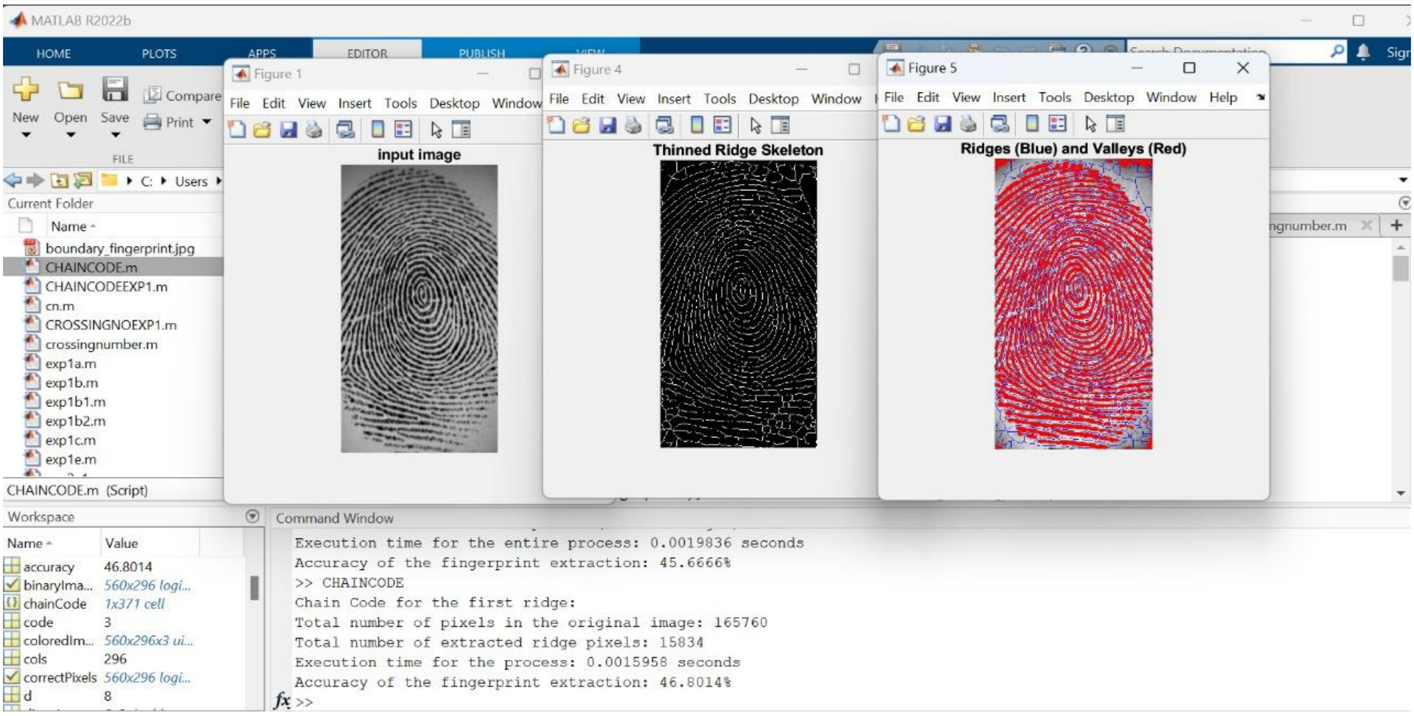

Fig 9 Output image

4.CROSSING NUMBER ALGORITHM:

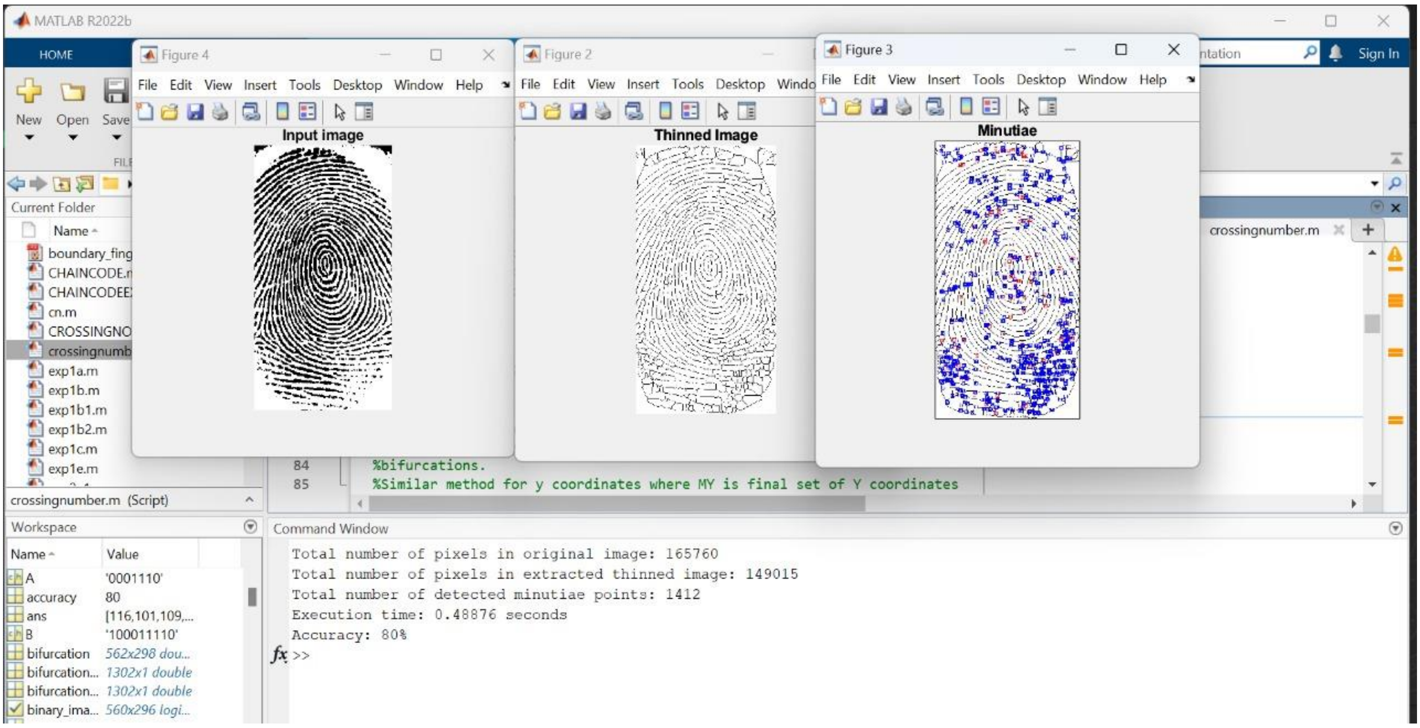

Fig 10: Output image

4.2 COMPARISION:

S NO.	ALGORITHMS	NUMBER OF MINUTIAE POINTS EXTRACTED (total=1,65,760)	EXECUTION TIME(IN SEC)	ACCURACY
1	ZHANG SUEN	16,745	0.0033	47.5%
2	MORPHOLOGY BASED	13,779	0.0014	45.66%
3	CHAIN CODE	15,834	0.0009	46.80%
4	CROSSING NUMBER	1,49,015	0.5439	80%

4.3 LIMITATIONS:

1. Variability in Fingerprint Quality

Low-quality fingerprints due to dry, wet, or dirty fingers can cause incomplete or inaccurate minutiae extraction.

2. Fingerprint Distortions:

Fingerprints often suffer from elastic deformations (e.g., pressure, rotation, and skew) during scanning.

3. Inconsistency Across Algorithms:

Each algorithm might use different minutiae detection methods (e.g., ridge thinning, ridge orientation analysis), leading to variations in detected minutiae points.

4. Partial Fingerprint Detection:

In cases where only a partial print is captured, algorithms might fail to extract enough minutiae points for comparison.

5. False Minutiae:

Algorithms can introduce spurious minutiae points, especially in noisy or low-quality prints. These false points can skew comparisons.

4.4 APPLICATIONS:

1. Biometric Authentication Systems

Access Control: Comparison of algorithms helps optimize fingerprint-based access control systems for secure entry into buildings, devices, or restricted areas.

Mobile Devices: Fingerprint recognition algorithms are compared to identify the most efficient for unlocking smartphones, laptops, and tablets.

2. Forensic Investigations

Law enforcement agencies compare algorithms to determine the most accurate methods for fingerprint analysis in crime scene investigations.

Minutiae extraction comparison ensures reliable matching of latent fingerprints found at crime scenes against criminal databases.

3. National Identification Systems

Governments implement fingerprint-based biometric systems for national ID programs, voter registration, passports, and border security. Algorithm comparisons ensure the selection of the most accurate and scalable solutions.

Examples: Aadhaar (India), e-Passports, or visa processing systems.

4. Banking and Financial Security

Fingerprint recognition is widely used for secure transactions, ATM access, and mobile banking apps. Comparing algorithms ensures reliability and reduces false positives or negatives in identity verification.

5. Healthcare Systems

Minutiae extraction algorithms are compared for use in patient identification and managing medical records. This ensures accurate retrieval of records and prevents duplication.

6. Employee Attendance and Workforce Management

Fingerprint-based attendance systems rely on minutiae extraction. Comparing algorithms helps in selecting systems that work effectively across diverse work environments (e.g., factories, offices).

7. Border Control and Immigration

At borders, algorithms are compared to ensure accurate fingerprint matching for immigration checks, passport verification, and traveler identity confirmation.

Fingerprint minutiae extraction algorithms are compared to integrate them effectively with other biometric modalities (e.g., face, iris, voice). This ensures higher accuracy in multimodal systems.

13. Cybersecurity
Fingerprint-based authentication systems are used in protecting sensitive digital assets. Algorithm comparisons ensure that fingerprint recognition algorithms minimize vulnerabilities.

14. Performance Benchmarking
Companies and institutions compare minutiae extraction algorithms to evaluate performance on criteria like accuracy, speed, false match rate (FMR), false non-match rate (FNMR), and scalability.

15. Customized Applications in Industry
Industries like manufacturing, retail, and education use fingerprint recognition systems tailored to their needs. Comparing algorithms ensures efficiency in deployment and operation.
8. Civil and Criminal Databases
Law enforcement agencies and other organizations compare extraction algorithms to improve the performance of Automated Fingerprint Identification Systems (AFIS).
This helps in large-scale fingerprint matching for identification and verification.

9. Access to Digital Platforms
Algorithms are compared to improve fingerprint-based authentication on platforms requiring secure logins, such as social media accounts, email, or cloud services.

10. IoT and Smart Devices
Internet of Things (IoT) devices increasingly incorporate fingerprint sensors for security. Comparing minutiae extraction algorithms ensures reliable performance on devices like smart locks, wearables, and home automation systems.

11. Research and Development
Researchers use algorithm comparison to evaluate the strengths and weaknesses of different extraction techniques. This supports the development
of new and more robust fingerprint recognition methods.

4.5 CONCLUSION AND FUTURE SCOPE

The comparison of fingerprint minutiae extraction algorithms highlights their critical role in biometric systems for accurate and reliable fingerprint recognition. Through this project, various algorithms were evaluated based on key performance metrics, such as accuracy, computational efficiency, robustness to noise, and handling of distortions or low-quality fingerprints.

The results demonstrate that the performance of minutiae extraction algorithms is influenced by factors such as image quality, preprocessing techniques, and alignment accuracy. Algorithms that incorporate effective noise reduction, ridge enhancement, and alignment correction consistently deliver better performance. Additionally, variations in detected minutiae points across algorithms emphasize the need for standardization and robust benchmarking frameworks.

This comparison provides valuable insights for selecting the most suitable algorithm for specific applications, such as forensic analysis, national identification systems, mobile authentication, and access control. Future work can focus on enhancing the algorithms' ability to handle partial prints, elastic distortions, and noisy images while maintaining computational efficiency for real-time applications.

In conclusion, fingerprint minutiae extraction algorithms are fundamental to modern biometric systems, and their comparison serves as a foundation for improving accuracy, scalability, and reliability in diverse real-world applications.

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