Design and Development of Fingerprint Recognition Technique using 3D Minutiae Matching Scheme

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Abstract- Fingerprints are the most potent authentic biometrics for personal identification, especially in forensic science. The two major types of 2D minutiae matching that are often applied for fingerprint recognition are ridge ending and bifurcation. This article focuses on employing a 3D Minutiae Matching Technique in conjunction with a 3D Template, commonly known as Minutiae Cylindrical Code (MCC). Cylinders, which are three-dimensional data structures, are the emphasis of this method. A lot of physical data has been shared in this digital era. The goal of this work is to increase the efficiency of fingerprint matching for this reason. We devised a method for reducing Matching Time, Enrolment, Time False Acceptance Rate (FAR), False Rejection Rate (FRR), and False Minutiae detection.

Keywords- MCC; FAR; FRR; MATCHING TIME; EXECUTION TIME; ENROLMENT TIME

I. INTRODUCTION

In an increasingly digital environment, personal authentication has become a key human-computer interaction activity. In many situations, such as national security, e-commerce, and computer network access, establishing a person's identification is critical. The majority of existing security measures rely on knowledge-based approaches like passwords or token-based tactics like swipe cards and passports to limit access. Such approaches, on the other hand, are insecure everywhere over the world. Pass cards and other tokens can be stolen or traded. Passwords and PIN codes that have been taken electronically pose a danger. They are still unable to distinguish between an authorised user and someone who has access to tokens or information. [1]

Biometrics, such as fingerprints, faces, and voiceprints, enable solid personal authentication that can alleviate these problems, and they are becoming more popular among citizens and governments. Fingerprint systems have been one of the most commonly investigated and deployed biometrics due to their ease of use, low cost of fingerprint sensors, non-intrusive scanning, and generally decent accuracy.

Fingerprints are the patterns on the skin of the fingertip. Fingerprints come in three different shapes: arch, circle, and whorl. The fingerprint is made up of valleys and ridges. The most evident structural characteristic of a fingerprint is the interleaved pattern of ridges and valleys. There are two distinctive properties of a fingerprint: a) Pattern of Global Ridges b) details of the Local Ridge.

A smooth pattern with alternating ridges and valleys makes up a fingerprint. The ridges don't run in a straight line; instead, they include a variety of defects known as minutiae. Essential minutiae information (typically ridge and Fingerprint Ridge ending and bifurcation positions and related orientations) is retrieved and saved in the database in the form of a template at the time of registration in the fingerprint system.

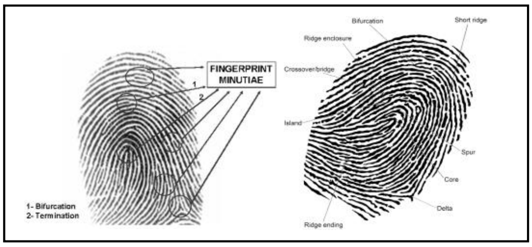


Figure 1.1 Local and Global Features: Minutiae, Core and Delta

Fingerprint matching is accomplished by comparing the precise distribution of two fingerprints using specific point pattern matching techniques. In forensic literature, minutiae have been extensively studied, especially in the context of fingerprint individuality models.

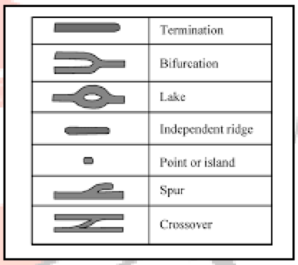


Figure 1.2 Seven most common Types of minutiae

Technological improvements have emerged from the fast adoption of digital technologies. In this information age, a great deal of physical data has been turned to digital data. An electronic identity card with digital fingerprint data is an example of how digital data can be used to identify a person. A tool that could be employed is fingerprint matching. There are three Approaches for fingerprint matching:

i) Correlation-based-matching.
ii) Pattern-based (or image-based) matching.
iii) Minutiae based matching.

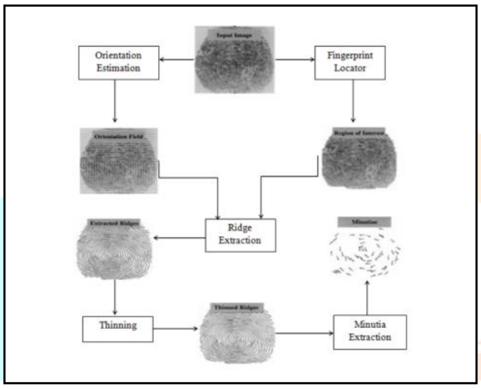
i) Correlation-based matching: For different alignments, two fingerprint pictures are superimposed and the correlation between corresponding pixels is obtained (e.g., various displacements and rotations). [2]

ii) Pattern-based (or image-based) matching: Pattern-based algorithms compare the basic fingerprint patterns (arch, whorl, and loop) between a previously stored prototype and a candidate fingerprint. For this to work, the photographs must be aligned in the same direction. The system accomplishes this by locating and focusing on a central point in the fingerprint image. In a pattern-based method, the template comprises the objects' form, scale, and orientation. The candidate's fingerprint picture is compared graphically to the template to see how closely they match. [2]

iii) Minutiae-based matching: The framework for fingerprint examiners' fingerprint correlations is based on this methodology, which is the most popular and widely employed. Minutiae are extracted and recorded as two-dimensional collections of points from the two fingerprints. The goal of minutiae-based matching is to determine the alignment that provides the most minutiae pairings between the template and the input minutiae sets.[3]

In Minutiae-based matching, there are two sorts of approaches: Minutiae based 2-D Approach: The minutiae, or ridge features, are retrieved and stored in a template for matching in this manner. It is unaffected by translation, rotation, or scale shifts. It is, nevertheless, prone to errors in low-resolution photos. The minutiae-based strategy is used. Image preprocessing is usually done prior to minutiae extraction. We should do the preprocessing and extraction stage before using the minutiae-based technique. To minimize noise and improve the clarity of ridges against valleys, fingerprint enhancement techniques are applied.[3]

Typical 2-D



Minutiae extraction process

a) Minutiae Cylinder code (MCC) based 3-D Approach: In the MCC representation, each minutia is associated with a local structure. The spatial and directional interactions between the minutia and its (fixed-radius) surrounds are represented as a cylinder in this structure, with the base and height corresponding to the spatial and directional details, respectively. [4]

Each cylinder is a local data structure:

- Invariant for translation and rotation;
- Robust against skin distortion (which is small at a local level) and against small feature extraction errors;
- With a fixed-length.

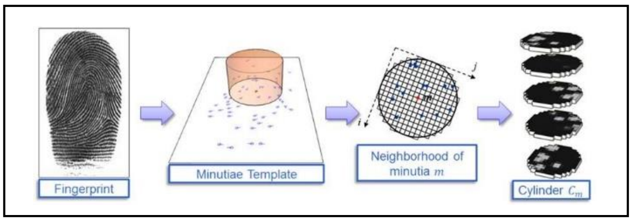


Figure 1.4: 3-D MCC Local Structures Representation

I. LITURATURE REVIEW

Many attempts have been made in the past and present to grasp this difficult idea of 2D and 3D fingerprint matching. A summary of these initiatives, as well as the approach and philosophy, is provided below:

Dr. Anil K. Jain et al. (2009) In their book "Handbook of Fingerprint Identification," they comprehensively describe all aspects of fingerprints and fingerprint recognition. [1]

David Maltoni (2005) In his work "A Tutorial on Fingerprint Recognition," he discussed fingerprint matching techniques. This course covers the fundamentals of fingerprint recognition systems, including sensing, feature extraction, and matching. The fundamental technologies are reviewed, as well as some cutting-edge algorithms. [9]

Raffaele Cappelli et al. (2010) The Minutia Cylinder-Code (MCC) was constructed as a new representation based on 3D data structures (called cylinders) generated from minutiae distances and angles. A subset of necessary elements provided by standards such as ISO / IEC 19794-2 (2005) can be used to make the cylinders (minutiae position and direction). They suggest that certain basic but effective metrics can be constructed to compute local similarities and aggregate them into a global score. MCC's supremacy over three well-known approaches is demonstrated in extensive tests in the FVC2006 databases, demonstrating the feasibility of offering light architectures with very powerful (and interoperable) fingerprint identification. [17]

Matteo Ferrara et al. (2011) To speed up fingerprint detection in huge databases, a contemporary hash-based indexing strategy is proposed. A Locality-Sensitive Hashing (LSH) approach was devised to be particularly effective in mapping a minutiae-based representation (position / angle only) into a set of binary vectors with fixed-length transformation-invariant in order to rely on Minutiae Cylinder-Code (MCC). A novel search strategy was created in addition to the numerical approximation of the similarity between the MCC vectors. Detailed tests have been undertaken to compare the proposed method with 15 current methodologies in all of the benchmarks typically used for fingerprint indexing. In almost all circumstances, the new strategy beats existing ones, despite the reduced set of features used (top performing approaches usually integrate more features). [13]

David Maltoni et al. (2012) Propose a two-factor authentication mechanism that makes P-MCC templates revocable. To prevent MCC templates from leaking confidential facts like the location and angle of minutiae, a secure MCC representation (dubbed P-MCC) was recently created. Despite a high level of precision and reversibility, P-MCC templates cannot be cancelled. [19]

M. Hamed Izadi et al. (2012) Propose an alternate approach for calculating cylinder quality measurements directly from fingerprint quality maps, particularly ridge clarity maps, while taking into account the number of minutiae involved. The integration of MCC with the proposed cylinder quality metrics was tested using the NIST SD27 Latent Fingerprint Database. These tests show that the efficacy of ugly-quality latent fingerprint detection has changed significantly. [12]

Matteo Ferrara et al. (2012) Propose a new safeguard for Minutia Cylinder-Code (MCC), a well-known local minutiae representation. The MCC is reversed using a sophisticated algorithm (i.e., to restore the initial minutiae positions and angles). Systematic experiments reveal that the new methodology outperforms state-of-the-art approaches in terms of precision while also providing adequate protection for detailed data and being resistant to masquerade assaults. [19]

A.Pasha Hosseinbor et al. (2017) suggest an iterative global alignment on two minutia sets for a minutia-based fingerprint matching system. The matcher evaluates all potential minutia pairings and aligns the two sets iteratively until the total number of minutia pairs does not exceed the maximum number of one-to-one pairings allowed. The best alignment parameters are calculated using linear least squares. [2]

WajihUllah Baig, et al. (2018Apply a change to the MCC descriptor's underlying details and show how, when employing other features, these changes have a significant impact on the precision of the matching. The MCC, which was originally a minutiae-only descriptor, is now a texture descriptor. The Short Time Fourier Transform (STFT) analysis is used to transform minute angular information into direction, frequency, and energy information. The minutiae texture cylinder codes are converted from the minutiae cylinder codes. (MTCC). The proposed enhancements to the MCC, based on a fixed set of parameters, show improved performance of the 2002 and 2004 FVC data sets and exceed the conventional MCC performance. [23]

TABLE I. Summary of Literature Review

Citation	Technique/Method	Approach	
		2-D	3-D
Asker Bazen M. et al. (2000)	Correlation-based	✓	×
Dr. Jain Anil K et al. (2000)	Filter bank based	✓	×
Tico Marius et al. (2003)	Orientation-Based Minutia Descriptor	✓	×
Koichi ITO et al. (2004)	Phase only correlation (POC) based	✓	×
Muhammad Munir et al. (2004)	Gabor Filters based	✓	×
Cappelli Raffaele et al. (2010)	Minutia Cylinder-Code (MCC) based	×	✓
Ferrara Matteo et al. (2011)	Minutia Cylinder-Code (MCC) based	×	✓
Maltoni David et al. (2012)	Minutia Cylinder-Code (MCC) based	×	✓
Ferrara Matteo et al. (2012)	Minutia Cylinder-Code (MCC) based	×	✓
M. Hamed Izadi et al. (2013)	Minutia Cylinder-Code (MCC) based	×	✓
Hosseinbor A. Pasha et al. (2017)	linear least square Method	✓	×
Baig Wajih Ullah, et al. (2018)	Minutia Cylinder-Code (MCC) based	×	✓

III. RESEARCH ISSUES

There are a number of unanswered issues in existing fingerprint-based biometric personal authentication research. The following are the most serious problems with fingerprint recognition systems:

i) Execution Time: This is assessed in order to determine the efficacy of the approaches. This is the amount of time it takes to collect data, compare it to database images, and provide results. This time is expressed in seconds. [16]

ii) False Acceptance Rate (FAR): This is the likelihood that the system will accept an invader. The number of times a fingerprint image is matched with an inaccurate database image is used to compute the likelihood. [16]

iii) False Rejection Rate (FRR): This is the likelihood that a genuine person will be denied down by the system. When an input image is chosen from one of the database photos, the probability is determined as the number of times a fingerprint image is not matched with any database image. [16]

The minutiae detection method must swiftly and precisely discover the minutiae points. Extraction of accurate minutiae points from a fingerprint, on the other hand, is a challenging task. Furthermore, there may be certain inconsistencies that further complicate the situation. The second problem is locating and eliminating fake minutiae.

IV. METHODOLOGY

The main goal of this research is to examine and implement existing 2-D fingerprint authentication techniques, design an effective and secure 3-D fingerprint authentication technique for personal authentication using Minutiae Cylindrical Code (MCC), and evaluate the performance of the designed framework by comparing it to the performance of existing 2-D fingerprint authentication techniques.

Data Sets used in research Work:

The performance evaluation of 3-D Fingerprint Matching method (MCC) with traditional 2-D matching method was done using the standard Fingerprint database provided by FVC (International Fingerprint Verification Competition-2004) by Biometric System Laboratory, DISI University of Bologna, ITALY (URL http://bias.csr.unibo.it/fvc2002/ default.asp.)

Model and design of the system:

The intent of this research work is that the model should be able to-

- To generate outputs for existing 2-D Fingerprint matching algorithms.
- To develop or improve existing 3-D Fingerprint matching algorithms (MCC).
- To reduce false minutiae.
- To reduce minutiae matching execution time.
- To achieve minimum FAR.
- To achieve minimum FRR

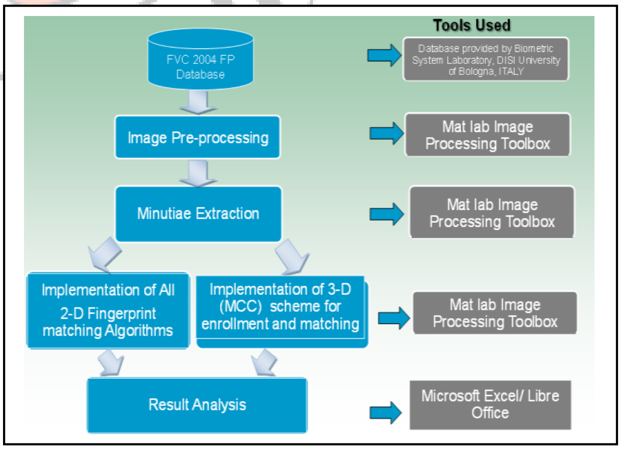


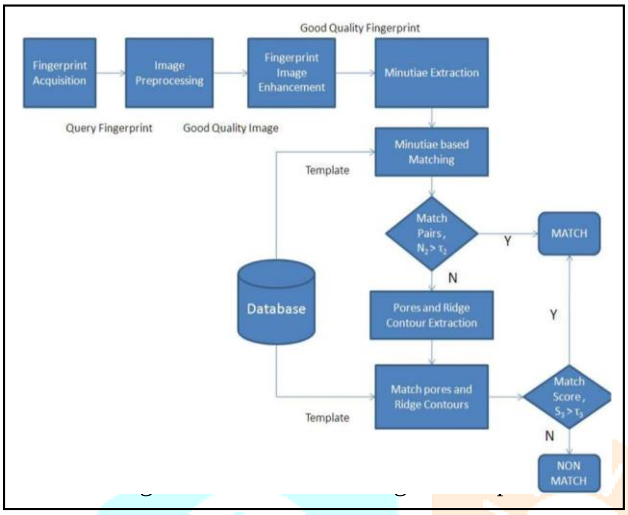
Figure. 4.1: Model of the system

Design Description:

The aforesaid framework is further separated into several modules and sub-modules, as shown in Figure 4.2. Preprocessing (image enhancement, image binarization, and image segmentation), Minutiae extraction (Ridge Thinning, and Minutiae marking), and Minutiae matching (Minutiae Alignment and Match procedures) are all part of the Minutia extraction process. The steps to execute this task are as follows mentioned

- Fingerprint Acquisition
- Fingerprint Image Enhancement

- Histogram Equalization
- Fingerprint Image binirasation
- Fingerprint Image Segmentation
- ROI Extraction by Morphological operations
- Minutiae Extraction
- Ridge Thinning
- Minutiae Marking
- Minutiae Representation
- Minutiae Matching



3.3 Minutiae matching Algorithm

Algorithm: Minutia-based Matching

Require: Qmap and Tmap

1: let M be the Hash Map containing matched minutia pairs (initially empty).
2: for all (m; vm) 2 Qmap do
3: for all (m0 ; vm0) 2 Tmap do
4: if m0 is already matched then
5: continue
6: end if
7: calculate edit distance between vm and v0m
8: end for
9: choose vm0 having minimum edit distance with vm
10: _nd the number of matching edges (nummatch) between vm and vm0 by using
a sequence alignment technique.
11: if nummatch > minmatch then
12: Insert (m;m0) in M fminmatch is a prede_ned constantg
13: end if
14: end for
15: return M

V. EXPERIMENTAL RESULTS AND ANALYSIS

The outline of our approach can be broadly classified into three stages -Acquiring device, Minutiae Extraction and Minutiae matching using 2D Gabor filter-based technique and 3D-MCC based technique.

The system takes one fingerprints as input to be match this fingerprint with another fingerprints, which already exist in database and gives a percentage score of the extent of match between the two. Based on the score and threshold match value it can distinguish whether the two fingerprints match or not.

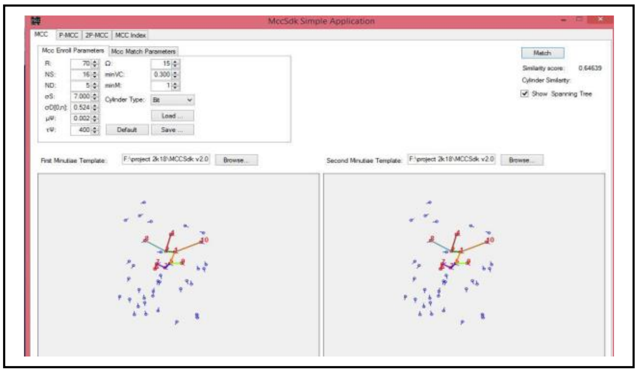


Figure 5.1: Fingerprint Matching

5.1 For Enrolment of Fingerprints: -

A Table was generated having Enrolment time for both enrolment time of all the 80 fingerprints we calculate set wise Average Enrolment time as

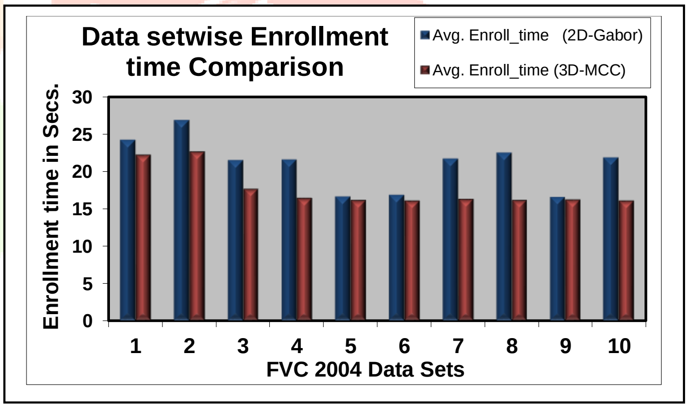
c = (b – a) (1)

Avg. Improvement = Avg. Enroll time (MCC) - Avg. Enroll time (Gabor Filter) (2)

Following formula computes Percentage Improvement in enrolment time.

d = [(c * 100) / a] (3)

Percentage Improvement = [[(Avg. Enroll time (MCC)-Avg. Enroll time (Gabor Filter.)] *100] / [Avg. Enroll _ time (MCC)]



(4)

Figure 5.2: Average Enrolment Time Comparison

5.2 For Matching of Fingerprints: -

Similarly, a Table was generated having matching time for both the approaches "for analysis purpose. Instead of using matching time of all the 80 fingerprints we calculate set wise Average matching time as

c = (b – a) (5)

Avg. Improvement = Avg. Match time (MCC) - Avg. Match time (Gabor Filter.) (6)

Following formula computes Percentage Improvement in enrolment time.

d = [(c * 100) / a] (7)

Percentage Improvement = [[(Avg. Match time (MCC) Avg. Match time (Gabor Filter.)] *100 / [Avg. Match time (MCC] (8)

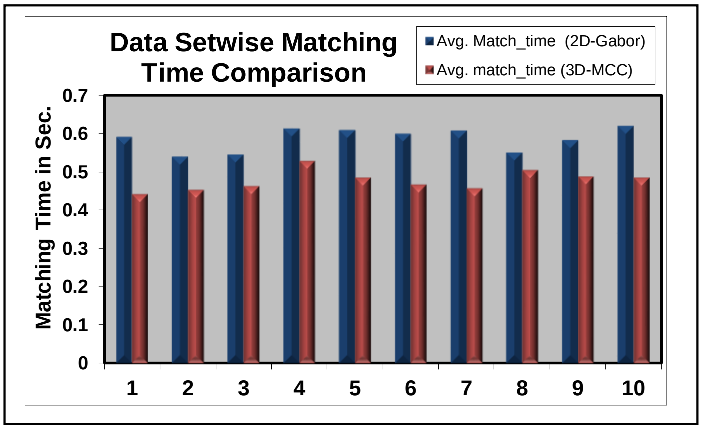


Figure 5.3: Average Matching Time Comparison

5.3 Performance Evaluation:

The performance evaluation of minutiae enrolment and matching scheme using 2D Gabor Filter approach and 3D-MCC approach is graphically represented in figure. 5.4 and Figure. 5.5 by comparing Average enrollment time and Average matching time.

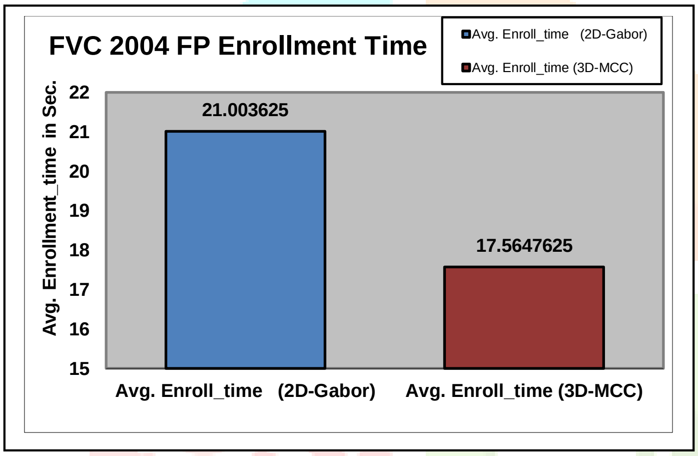


Figure 5.4: FVC 2004 data set AVG. Enrolment Time Comparison

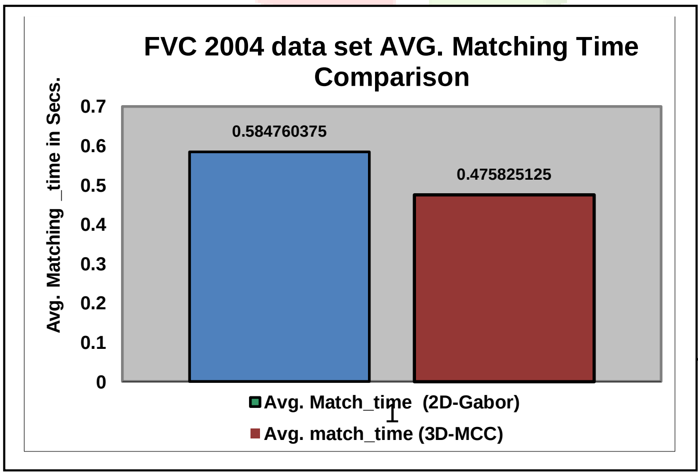


Figure 5.5: FVC 2004 data set AVG. Matching Time Comparison

Similarly, the model was used to compare False acceptance rate (FAR), False rejection rate (FRR) and Detecting False Minutia. Graphically the performance analysis can be represented as.

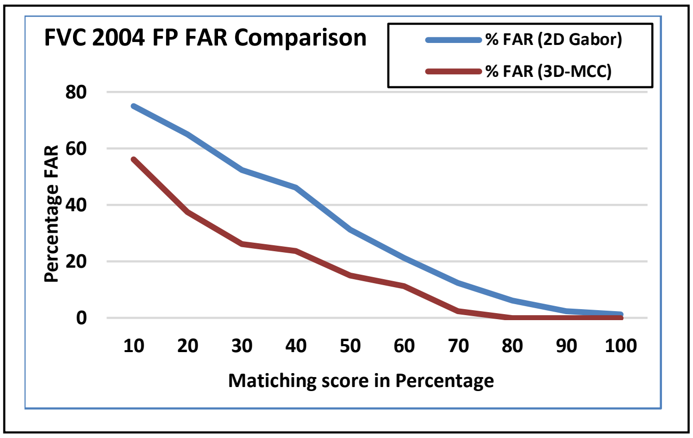


Figure 5.6: False Acceptance rate Comparison

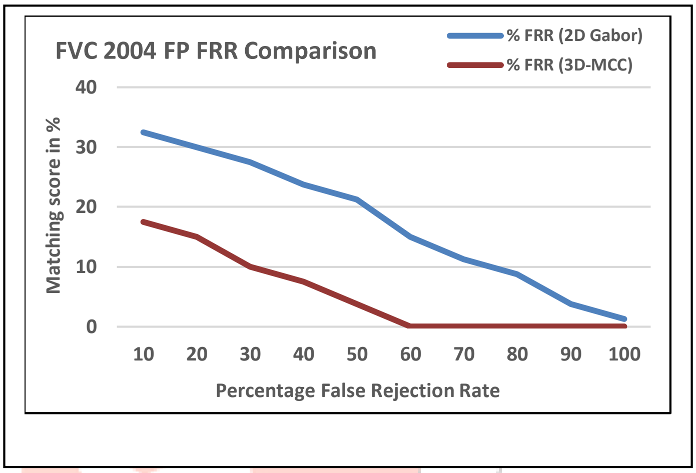


Figure 5.7: False Acceptance rate Comparison

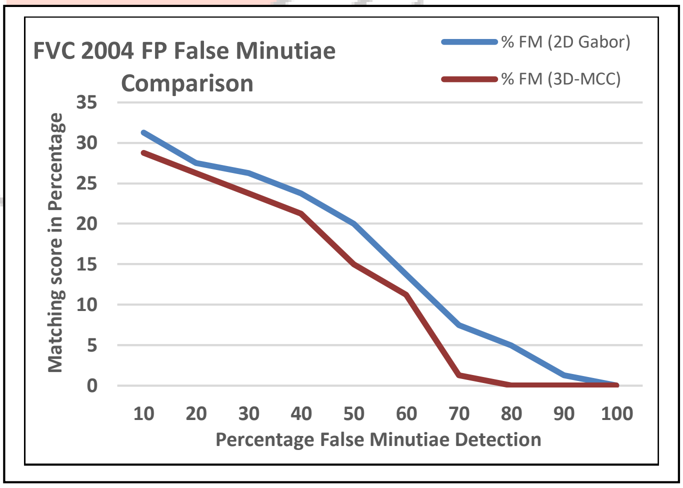


Figure 5.8: False Minutiae Detection Comparison

VI. CONCLUSION

Thus, this work will help in building technique that would reduce the execution time for Fingerprint enrolment and matching. Also, it will reduce False Acceptance Rate (FAR), False Rejection Rate (FRR) and detecting False Minutiae. It will allow other researchers to uncover the accuracy of fingerprint recognition systems that are important in Biometric Systems that might not be uncovered by any other methods.

System was implemented using MAT LAB and from the obtained results, we can conclude that, the performance of 3D-MCC using above technique is found to be improved by 16.33% for Enrolment, and 18.64 % for Matching of fingerprints respectively. Similarly Fault Acceptance Rate (FAR) was reduced by 35.4 %, Fault Rejection Rate (FRR) was reduced by 18.9% and False Minutiae detection was reduced by 54 %. which is found to be substantial.

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