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# A Ratio-Based Hierarchical Fingerprint Recognition System

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**Abstract-**Fingerprint Recognition is a complex pattern recognition problem. It is intricate to design precise algorithms for extracting significant features and matching them in a robust way. The main challenge is matching fingerprints affected by: i) non-linear distortion, ii) high displacement/or rotation, iii) different pressure and skin condition and iv) feature extraction errors. In this paper the above mentioned problems have been addressed and a new ratio-based hierarchical matcher has been proposed. The intend is to reduce the false acceptance rate and false rejection rate in the existing minutiae based systems. The ratio-based hierarchical matcher has been tested on two diverse databases in public domain. The obtained result shows potential and verify my claim.

**Index Terms**- Fingerprint verification, fingerprint matching, ratio-based hierarchical matcher.

## 1. INTRODUCTION

Biometric based recognition, or biometrics, is the science of identifying, or verifying the identity of, a person based on physiological or behavioral characteristics [4]. Physiological features are related to the physiology of the body and mainly include fingerprint, face, ear, iris, retina, DNA, hand and palm geometry. A biometric attribute cannot be easily transferred, forgotten or lost, the rightful owner of the biometric template can be easily identified, and it is difficult to duplicate a biometric feature [5]. There are a number of desirable properties for any chosen biometric characteristic [4]. These are: universality, uniqueness, permanence, collectability and acceptability. A biometric system is basically a pattern recognition system that operates by acquiring biometric data from an individual, extracting a feature set from the acquired data, and comparing this feature set against the template set in the database [8]. The effectiveness of a biometric system can be judged by its performance, scalability, non-invasiveness and circumvention.

## 2. BACKGROUND

Fingerprints have been found on ancient artifacts' recovered from excavation sites of various civilizations [10]. However fingerprints have been used for identification only from nineteenth century onwards. A time-line of important events that has established the foundation of the modern fingerprint based biometric technology is found in [1]. Henry Fauld has first scientifically suggested the eccentricity and uniqueness of fingerprints [6]. Sir Francis Galton has published the well-known book entitled Fingerprints [7], in which a detailed statistical model of fingerprint analysis and identification has been discussed. Galton has introduced Level 2 features by defining minutiae points as either ridge endings or ridge bifurcations on a local ridge. An important advance in fingerprint identification has been made by Edward Henry, who has established a system known as "Henry system" for fingerprint classification [12].

In [11], Locard has introduced the science of "poroscopy", the comparison of sweat pores for the purpose of personal identification. Locard has stated that like the ridge characteristics, the pores are also everlasting, immutable, and unique, and are useful for establishing the identity, especially when a sufficient number of ridges is not available. Chatterjee has proposed the use of ridge edges in combination with other friction ridge formations to establish individualization, which is referred to as "edgeoscopy" [3].

A fingerprint is an impression of the ridges, from the surface of a fingertip. Fingerprints have been used for personal identification purpose for many years. Recently it becomes automated due to improvement in computing capabilities. Fingerprint recognition is the most popular biometric technologies mainly because of the inbuilt ease in acquisition, the abundant sources (ten fingers) available for collection, and the traditional use and collections by law enforcement agencies. Automatic fingerprint identification is one of the most reliable biometric technologies. This is because of the well known fingerprint individuality, perseverance, ease of acquisition and high matching accuracy rates. Fingerprints are unique to each human being and they do not change over time. Even twins do not carry identical fingerprints. The ridge patterns and details in small areas of friction ridges are never repeated. These friction ridges develop on the fetus in their definitive form before birth and are known to be persistent throughout life except for permanent scarring. Scientific research in areas such as biology, anatomy, embryology and histology has supported these findings [2]. Also, the matching accuracy of fingerprint based authentication systems are generally very high. Fingerprint-based authentication systems continue to dominate the biometrics market by accounting for almost 52% of authentication systems based on biometric qualities [9].

The various stages in a fingerprint verification system is shown in Figure 1.

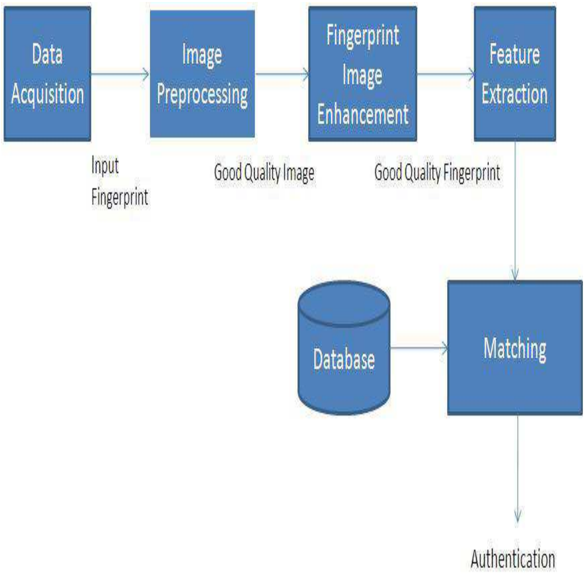


Fig. 1. Architecture of a Fingerprint Verification System.

It is known that fingerprint matching is the most important stage in fingerprint recognition process. A fingerprint matching algorithm compares two sets of features derived from two fingerprints and determines whether or not they represent the same finger. Fingerprint matching is an extremely difficult problem, mainly because of the large intra-class variations that exists in different impressions of the same finger. The main factors responsible for these intra-class variations [9] are: i) Displacement and Rotation: The same finger may be placed at different locations and at different orientation on the sensor in the time of different acquisitions which results in a (global) translation and rotation of the fingerprint area. ii) Partial overlap: Finger displacement and rotation often cause part of the fingerprint area to fall outside the sensor's field of view, which results in a smaller overlap between different impressions of the same finger. iii) Non-linear distortion: The act of sensing maps the three-dimensional shape of a finger onto the two-dimensional surface of the sensor. This mapping results in a non-linear distortion in consecutive acquisitions of the same finger for finger skin plasticity. iv) Pressure and skin condition: The ridge structure of a finger would be accurately captured if ridges of the part of the finger being imaged were in uniform contact with sensor surface. However, dryness of the skin, finger pressure, sweat, skin disease, dirt, grease and humidity in the air all stun the situation, which results in a non-uniform contact. As a result, the acquired fingerprint images are very noisy. v) Feature extraction errors : The feature extraction algorithms are not perfect and often bring in measurement errors. For example, in low quality fingerprint images, the minutiae extraction process introduces a large number of spurious minutiae. Also it does not detect all the true minutiae.

## 3. PROPOSED WORK

Level 3 features are known to carry discriminative information and forensic examiners often make use of Level 3 features when insufficient minutia points are present. A new ratio-based hierarchical matching system which utilizes additional information in form of Level 3 features (pores) has been proposed in this paper. Figure 2 in the next page illustrates the architectural design of the proposed system.

The correlation based method requires the complete image to be stored (large template sizes). The texture based methods are less accurate than minutiae based matchers since most regions in the fingerprint carry low textural content. Both types of methods requires accurate alignment of fingerprints. The minutia based techniques on the other hand are more accurate and they very closely resemble the manual approach as used by forensic experts.

Studies have shown that by combining additional information in the form of texture features, level 3 features with minutia based matcher, higher accuracy can be achieved. The minutia based approaches like other approaches cannot give a high confidence match when the images are of poor quality or when there is a very small overlap i.e. very few minutia points are available for matching.

In my paper, I have identified that the real challenges in fingerprint matching are high displacement or rotation, non-linear distortion, different pressure and skin condition and feature extraction errors. Among them, non-linear distortion affects the query fingerprint most. By going through many contemporary thesis papers on fingerprint matching, I have found that non-linear distortion can be minimized to a greater extent if we match the fingerprints on the basis of local structure i.e. local matching. For this reason in my proposed work, in every aspect, I have tried to use local structure-based matching, not the global structure based matching.

Let $Q$ and $T$ be the query and template fingerprint

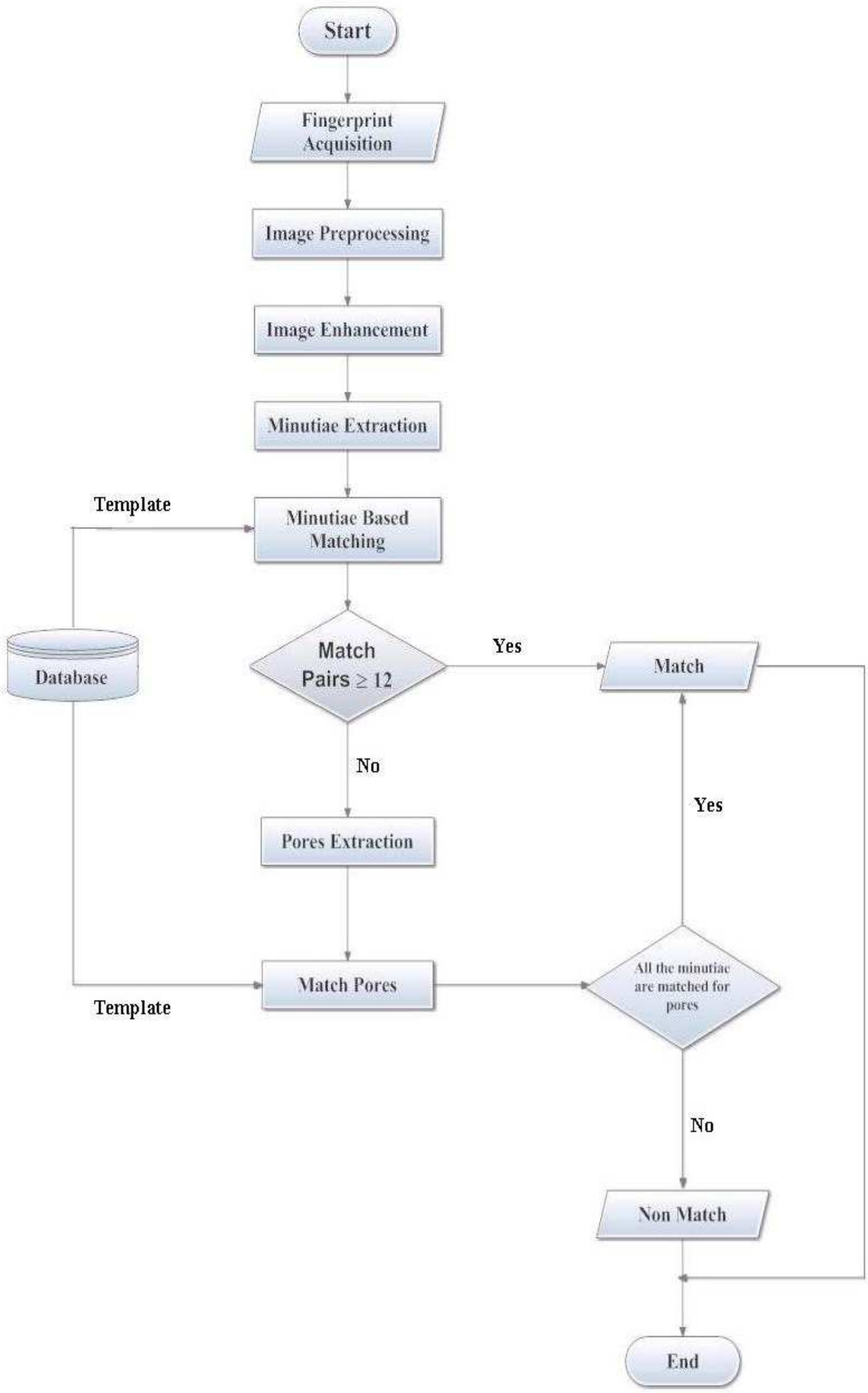


Fig. 2. The proposed ratio-based hierarchical matcher.

images which are to be matched. At first, the minutiae based i.e. level 2 feature based matcher matches *Q* and *T* and return the matched minutiae pairs, which is a measure of degree of similarity between two fingerprints. Let *N*, be the number of matched minutiae pairs returned by the minutiae based-matcher. If $N \geq 12$(the figure 12 is determined by the Court of Authorities of various countries), the query and template fingerprints are considered "matched" and the matching terminates.

Let $N < 12$, then the matching continues and level 3 features based matcher further matches the two fingerprints and returns the final match or non-match decision. The matched minutiae at level 2 are further examined and the level 3 features in their neighborhood (a small area around minutiae) are matched.

### 3.1. *Minutiae-Based Matcher*

I have proposed a local structure based minutiae matcher. It consists of a reference or central minutiae point $m_i$ and its two nearest neighboring minutiae points $m_{i1}$ and $m_{i2}$ within a local neighborhood. The local structures corresponding to reference minutiae points are checked for matching. At the end of this stage pairs of matching minutiae points are returned. During this stage the "local structures" in *Q* are matched with the "local structures" in T. If two local

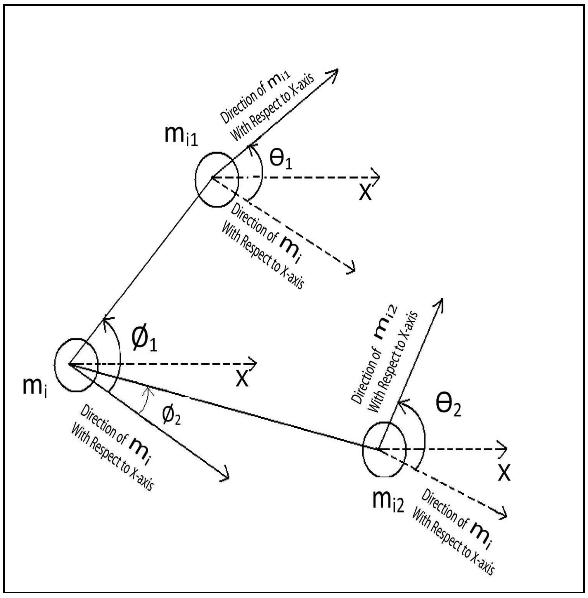


Fig. 3. The schematic description of my proposed local structure.

structures in *Q* and T are found to be matched then the minutiae representing their centers are also considered to be matched. A local structure with a central minutiae *m* and with two nearest neighboring minutiae is represented by a two element feature vector $V_m$.. Each element $V_{mi} \epsilon V_m$ $( i = 1,2 )$ is a 3-tuple $( r_i , \theta_i , \varphi_i )$ representing the radial parameters of *ith* neighboring minutiae with respect to central minutiae *m*.

$$V_m = \{V_{m1}, V_{m2}\}$$
$$= \{( r_1 ,\theta_1,\varphi_1 ) , ( r_2 , \theta_2,\varphi_2 ) \}$$

Here,
$r_i$ is the distance of *ith* neighboring minutiae from m,
$\theta_i$ is the orientation of *ith* neighboring minutiae with respect to *m*'s orientation,
$\varphi_i$ is the direction difference between *m*'s orientation and the direction of the edge connecting *m* and $m_i$.

The "local structure" which I consider is invariant to rotation, translation, scaling and elastic or non-linear distortion and thus any type of alignment is not required. The local structure matching problem thus reduces to matching two ordered sequences.

$$V_m = \{V_{m1}, V_{m2}\} = \{( r_1 , \theta_1 , \varphi_1 ) , (r_2 , \theta_2 , \varphi_2) \}$$
$$V_m' = \{V_m'_1, V_m'_2\} = \{( r'_1 , \theta'_1 , \varphi'_1 ) , (r'_2 , \theta'_2 , \varphi'_2)\}$$

Where, $V_m$ represents a local structure in *T* and $V_m'$ represents a local structure in *Q*.

I have used a unique procedure to determine the distance between the reference or central minutiae and the two nearest neighboring minutiae. In each of the previous paper all the authors simply determine the distance between central minutiae and *ith* neighboring minutiae in both query fingerprint *Q* and template fingerprint *T*. Then they try to match the measured distances. In case of non-linear distortion, rotation or displacement and scaling the measured distance between central minutiae and two nearest neighboring minutiae in both *Q* and *T* may vary. So a local structure which should be matched in *Q* and *T*, may not match in case of non-linear distortion, rotation or displacement and scaling. I have eradicated this problem by taking the ratio of the distances. In this case I have used a hypothesis. The hypothesis can be expressed as: due to non-linear distortion, rotation or displacement and scaling the measured distance between reference or central minutiae and two nearest neighboring minutiae may change, but they will change in a way that the ratios of distance between $( m_i , m_{i1} ), m_i , m_{i2})$ and $(( m'_i ,m'_{i1}), ( m'_i , m'_{i2})$ will not change. Let us explain this with the help of some schematic diagram which are placed in the next page.

$$V_m = \{V_{m1}, V_{m2}\} = \{(2.9,45°,30°),(3.6,75°,300°)\}$$
$$\text{Here, } r_1/ r_2 = 2.9/ 3.6 = 0.81$$

$$V_m' = \{V_m'_1, V_m'_2\} = \{(3,45°,30°),(3.7,75°,300°)\}$$
$$\text{Here, } r'_1/ r'_2 = 3/3.7 = 0.81$$

Since, local structures with feature vectors $V_m$ and $V'_m$ match in every radial parameters, we can say that $V_m$ and $V'_m$ match. Thus, reference minutiae point *m* in *T* and reference minutiae point m′ in *Q* also match.

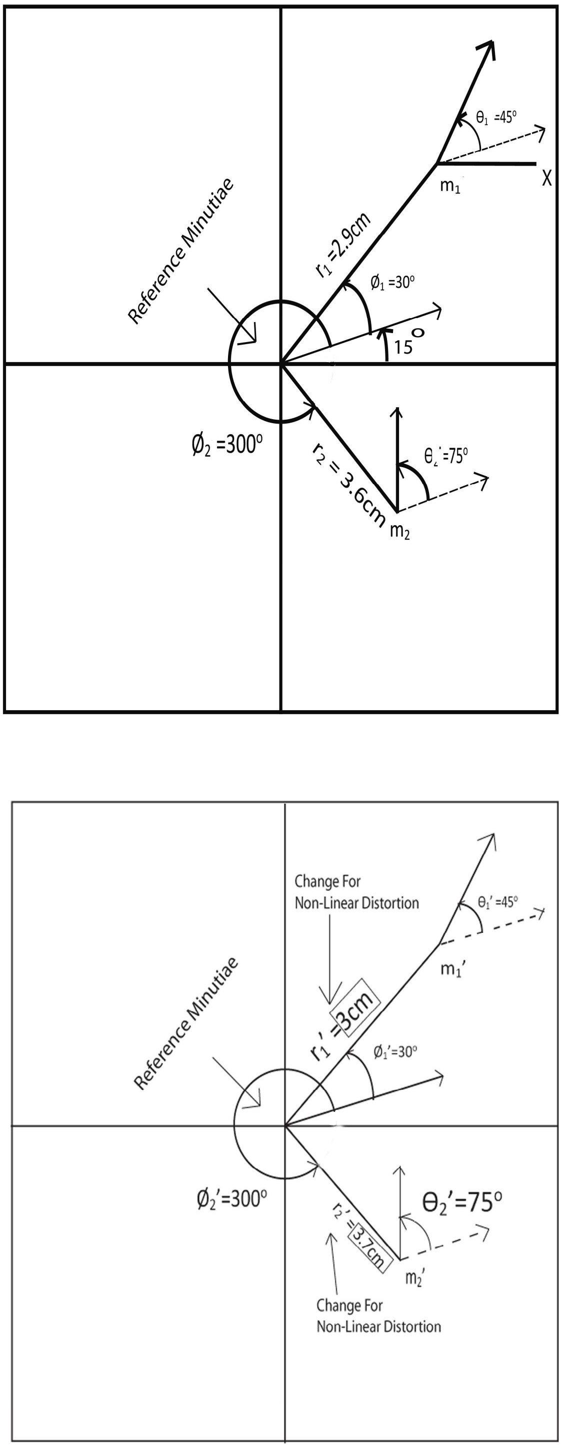


Fig. 4. Template fingerprint *T* and Query fingerprint *Q*.

So, the pair *(m, m´ )* is returned as a matching pair. In the above way, I try to match every minutiae in *Q* with every minutiae in *T*. If number of matching pairs ≥ 12, then we conclude that the query fingerprint *Q* and template fingerprint *T* are two impressions of the same finger. If number of matching pairs < 12, matching continues to level 3.

### 3.2. *Level 3 Feature-Based Matcher*

The matched minutiae pairs at level 2 are examined again and level 3 features in their neighborhood are compared. Thus, for a given pair of matched minutiae, I compare the level 3 features in their neighborhood and the minutiae correspondence (connection/ relation) is recomputed based on the agreement of level 3 features. Pores and ridge contours are two elegant level 3 features. From the literature of fingerprint, we know that if either of pores or ridge contours agree then the minutiae correspondence is verified.

As with level 2 matching in level 3 matching I use local structure to tolerate the effect of non-linear distortion. In my proposed work, I include only pore matching since either pores or ridge contours are sufficient to check minutiae correspondence.

### 3.3. *Pore Matching*

Each pore is represented by a 3-tuples *(x,y,θ)*, where *x, y* denote its location and θ is the direction of the ridge, at the location where it lies. Mayank Vatsa et al, Jonathan D. Stosz et al and A. k. Jain et al have used only location information of pores for matching. Similar to minutiae, pores maintain the same relative orientation to other pores within a fingerprint between different impressions. In a fingerprint pores are distributed over ridge and associating direction information with pores provides additional information for matching. I propose a novel approach for matching pores.

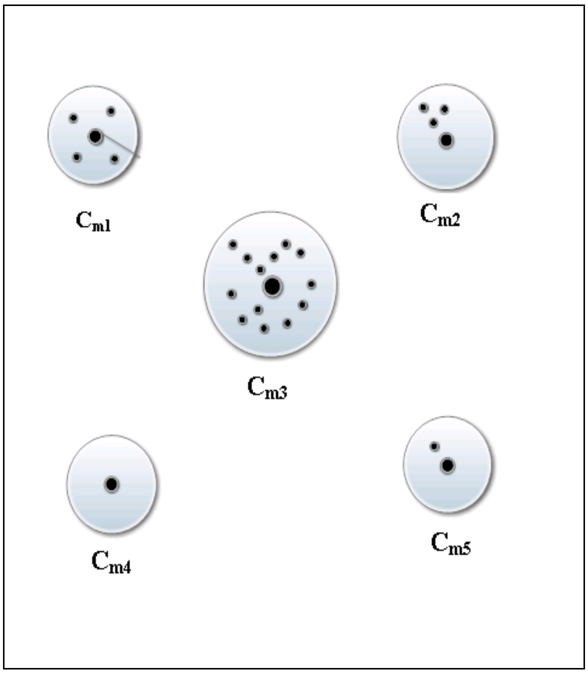


Fig. 5. Template fingerprint image with number of matched minutiae pairs = 5.

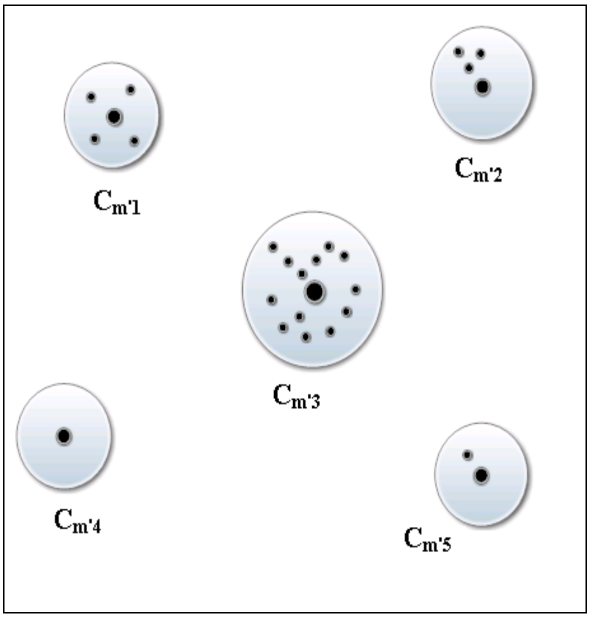


Fig. 6. Query fingerprint image with number of matched minutiae pairs = 5.

Pores within a circular region $C_m$ around the matched minutiae points, obtained from minutiae-based matcher, are used for matching. The radius of the circular region is chosen as the distance between the matched minutiae and its nearest neighborhood minutiae in both *T* and *Q*. Then I implement the same approach in the circular region which I implement for level 2 matching. If every pore in $C'_m$ in *Q* has a corresponding pore in $C_m$ in *T*, then I conclude that, the minutiae m′ in *Q* which has matched with minutiae *m* in *T* in level 2 feature-based matching, is also matched for level 3 matching. In this way, I try to find correspondence between each matched minutiae $m'_i$ and $m_i$ in *Q* and *T* for level 3 feature-pores. If every matched minutiae in *Q* and *T* are also matched for level 3 feature-pores, then I conclude that *Q* and *T* are two impressions of the same fingerprint image. Otherwise, I decide that they are two impressions of two fingerprints, i.e. non-match.

First, I will try to match each pore in $C_m{'}_1$ with each pore in $C_{m1}$ by using my proposed work. If every pore in $C_m{'}_1$ has a corresponding pore in $C_{m1}$, then I conclude that minutiae $m'_1$ in *Q* is matched with minutiae $m_1$ in *T* for level 3 feature-pores. In this way, I will try to find match for rest of the minutiae in *Q* with rest of minutiae in *T*. If all the minutiae are matched for level 3 feature pores, then I decide that, the two fingerprint images are matched although number of matched minutiae pairs < 12. Otherwise non-match.

## 4. EXPERIMENTATION

I have developed a simulation software using MATLAB(R2009a). It is a complete software by which I can perform a complete fingerprint verification. In this software I have utilized some standard code to extract minutiae information from fingerprint image. Then I have developed my own code to match the template and query fingerprint images. The evaluations and testing of the proposed approach has been done on two diverse fingerprint databases: FVC2002 Database and FVC 2004 Database.

## 5. CONCLUSION

A new ratio-based hierarchical fingerprint matcher which utilizes Level 3 features(pores) in conjunction with Level 2 features(minutiae) has been proposed in this paper. The novelty lies in the matching technique used for matching Level 2 features (minutiae) and Level 3 features (pores). Based on my observations and obtained results it can be concluded that use of Level 3 features(pores) with Level 2 features(minutiae) reduce false acceptance rate and false rejection rate. I have successfully used localized matching for matching all feature types, in-order to minimize the effects of distortion. The technique used in this paper for matching prevents the use of any type of alignment(registration) at any stage. The concept of this paper can be used in automated fingerprint verification system with better performance.

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