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Fingerprint Recognition Technology Using Deep Learning: A Review

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Abstract: With the development of technology there has been an increase in the need of biometrics due to the existence of technological advancements in bypassing and hacking methodologies. A fingerprint recognition technology helps to overcome these technological barriers. A fingerprint recognition technology refers to the process of identifying or confirming the identity of an individual by comparing two fingerprints. It is the most researched and reliable biometric technique for identification and authentication. It is highly accurate, unique and can never be same to two persons. Fingerprint is the pattern that is found on the fingertip. This paper presents the study of various fingerprint recognition technology using deep learning such as Minutiae verification which helps to get the point of interest in a fingerprint with various methods and techniques, Core point detection based system which has a orthogonal gradient magnitudes of orientation field and CNN algorithm which is applied to analyze visual imagery which is a deep neural network.

Keywords: Fingerprint, Minutiae, Ridges, neural networks, CNN, bifurcation, etc.

1. INTRODUCTION

The unique features of an individual up to now are the biometric identifier such as fingerprint, iris, DNA structure, facial patterns and voice or typing cadence. A biometric identifier is related to the intrinsic human characteristics. Fingerprint is the most common and wide spread biometrics used due to the arrival of smart phones. Any surface that can be touched such as smart screen, door panel, and a touch pad or computer mouse has become an easy and adaptable fingerprint recognizer.

Fingerprint recognition technology has a long history which was mostly used for the identification of the criminals from a crime scene and judicial investigations. Until 19th century fingerprint were not used as a method for identifying criminals. In 1858, the chief magistrate of Hooghly district in Jungipoor, India Sir William Hershel had residents recorded fingerprints of criminals when signing business documents. After few years, a Scottish doctor Henry Faulds were working in Japan found fingerprints left by artists on

ancient pieces of clay inspired him to investigate more on fingerprints. Henry Faulds is said to be the pioneer in fingerprint identification but his role in this field was not appreciated in his lifetime. The raise in the technology made an impact in the people's daily life with fingerprint as an important authentication system. The fingerprints have different patterns which are made by the combination of several dermal ridges. These ridges are developed during the time in the womb, where several factors such as friction, maternal conditions, etc affect the final shape and structure. These patterns develop all over the human body, including the palms, soles, and even toe [1]. These are the reason in which we consider fingerprint patterns as a unique feature of an individual.

The aim of this paper is to study the various algorithms and techniques or methods for the fingerprint feature extraction and matching. This paper is organized as follows: In the first session the attributes of fingerprints are discussed. In the next session, features of fingerprint are described. The next session gives all the technologies used for the fingerprint feature extraction and matching. The next session gives the database available for the fingerprint extraction technology. In the next session, the outcomes of algorithms used in literatures and gives the results from different papers on the theme. In the last session advantages and disadvanges followed by the conclusion and list of references are discussed.

2. ATTRIBUTES OF FINGERPRINT

A fingerprint is an impression of a fingertip made on any plain or flat surface. Also it can be said as an ink impression of the lines upon the fingertip which is further used for identification. A fingerprint consists of ridges and valleys. Ridges are the dark area of the fingerprint and valleys are the white area between the ridges. There are mainly three major types of fingerprints The Arch, The Whorl and The Loop.

Fig. 1: Fingerprint pattern with its various attributes

2.1 The Arch

This is the rarest fingerprint and is about 5% of the world's population having this pattern. Cores and delta lacks in the Arch which makes it unique. There exits two sub- categories with The Arch pattern Plain Arch and Tented Arch.

- Plain Arch: Plain Arch has raised ridges which are extended from one side to the other side of the

fingertip in a continuous pattern. It rarest and is approximately 5% of the total population.

- Tented Arch: Tented Arch also have raised ridges with continuous pattern as in the plain arch which is the similar feature of the plain arch and tented arch. Tented arch has pitch of the raised edge which has sharper ege than the plain arch which forms a tent like structure which makes the difference.

Fig 2: Plain Arch and Tented Arch

2.2 The Whorl

The Whorl fingerprint pattern covers 25 to 35 percent of the total population. The Whorl has core and two deltas which is the unique feature of the whorl. The similar feature of whorl with arch is the categorization. The Whorl can be categorized into two Plain Whorl and Central Pocket Whorl.

- Plain Whorl: a swirl or a spiral like structure is represented as a plain whorl which is in circular pattern. This circular pattern is unbroken. At least a single ridge results in the revolution formed at the centre.
- Central Pocket Whorl: The Central Pocket Whorl will have a smaller inner whorl with curves more than once, which is a central ridge.

Fig 3: Plain Whorl and Central Pocket Whorl

2.3 The Loop

The Loop is the most common and popular fingerprint pattern with 60 to 70 percent of the total population. The Loop pattern will have at least one core and delta. The Loop pattern can be classified into three types Ulnar Loop, Radial Loop and Central Pocket Loop.

- Ulnar Loop: Ulnar Loop pattern will have ridges turning in backward direction which has no full turn. Ulnar Loop pattern are found in small finger.
- Radial Loop: Radial Loop is similar to the Ulnar Loop but it is found in the thumb.
- Central Pocket Loop: the Central Pocket Loop patterns have ridges which re-curve to surround the central

whorl.

Fig 4: Ulnar Loop, Radial Loop and Central Pocket Loop

2.4 Other Attributes of Fingerprint

- Double Loop Whorl: The Double loop Whorl consist of two separate loops surrounds from each other in different directions.

Fig 5: Double Loop Whorl

- Accidental: These are the patterns which douse not match with all the above mentioned patterns. These Patterns contain Tented Arch, Loop or Whorl patterns.

Fig 6: Accidental

- ❖ **Ridges:** In a finger image a ridge is the curved line. Some rides are continuous curves and some of the ridges terminate a specific point called Ridge endings. Two ridges joins together at a point called Bifurcation.
- ❖ **Minutiae:** Bifurcation and Ridges ending are together called as Minutiae. The number and position of minutiae vary from finger to finger of a person and also vary from person to person of any particular finger.

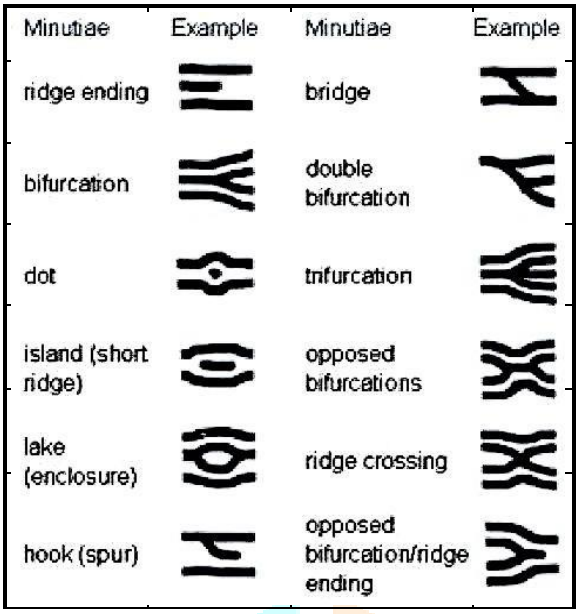

Fig 7: Ridges where minutiae points are considered

3. FEATURES OF FINGERPRINT:

Fingerprint Recognition means extracting different features of fingerprint during enrolment phase and matching these features during identification phase [2]. The features of fingerprint are parameters in the epidermis images seen in the fingertip which can be used to extract information for a unique person.

3.1 Local Features

These features are the unique features. These features are used for the unique characterization such as minutia points.

Global Features

These are the features which can be visualized by a human with naked eyes. The global features include core points, type lines delta and so on.

3.2 Very fine level features

These features include intra ridge details such as sweat pores.

Some other features includes the following,

- The high accuracy of fingerprint.
- It can be never same for two persons.
- It is the most economical technique.
- It is easy to use and use small storage space.

4. TECHNOLOGIES:

There are many technologies available for fingerprint recognition technology.

4.1 Fingerprint Minutiae Extraction

The point of interest in a fingerprint is known as Minutiae which includes bifurcations and ridge endings. Minutiae points are in a simplified sense, points where fingerprint ridge-lines either end (ridge-endings) or split (bifurcations) [3]. It's about 40-100 minutiae are found in a good quality fingerprint. A partial or poor quality fingerprint has an approximate of 20- 30 minutiae. The minutiae based fingerprint recognition is the most accurate method. It is the backbone of most currently available fingerprint recognition products.

Since the original image of fingerprints cannot be reconstructed using only minutiae, the minutiae based technology assists privacy issues and the minutiae are only needed to prove fingerprint individually. The fingerprints are more stable in contrast, image resolution and global distortion. The first challenge lies in extracting minutiae from a latent image. It's important to enhance the fingerprint images before minutiae matching. These extractions are of two categories,

- Methods that work directly on gray scale fingerprint images.
  - The following diagram shows different categories of extraction,

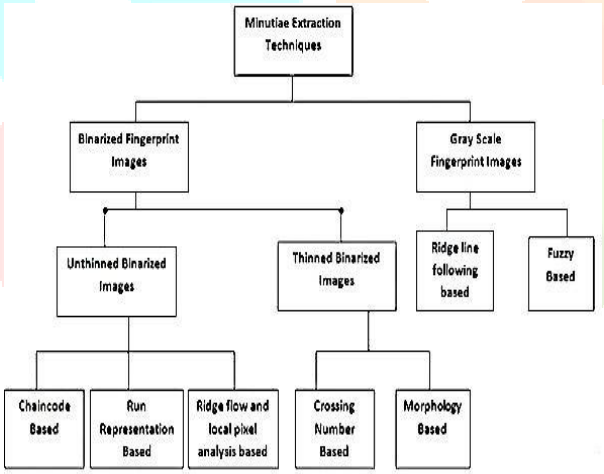

Fig 8: Classification of Minutiae extraction techniques

4.1.1 Unthinned Binarized Images:

It has three methods of extraction,

- Chain Processing: Transitions from white background to white foreground are identified by scanning the image from top to bottom and right to left. It is further expressed as an array of contour elements by tracing the contour counter clockwise and represents a pixel on contour. By tracing a ridge line along the boundary counter clockwise, a minutiae ending is located when the ridge line makes a significant left turn. Similarly if the trace makes a left turn bifurcation minutiae is found.
- Run Representations based methods: The image is pre-processed for enhancement. The image is extracted

from the background by segmenting and normalized to have predefined mean and variance. Local orientation and ridge frequency around each pixel is calculated which is applied into Gabor Filter (texture analysis) to enhance ridges orientation in the local orientation direction. Hence the contrast between the foreground and background increases and the noise effectively reduces. The next process is the image binarization in which the threshold value is selected as pixels having values above the threshold as white and others as black. For each image region an optimal threshold value is selected in adaptive image binarization and hence the minutiae are extracted.

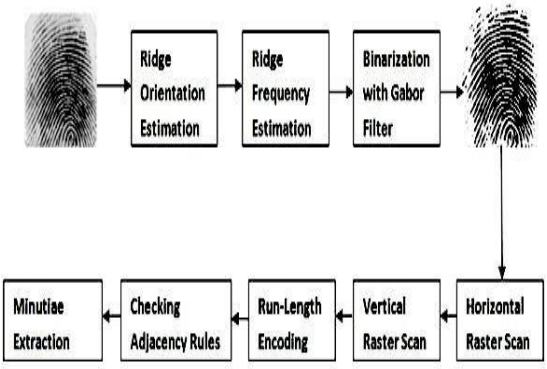

Fig 9: Block Diagram of Minutiae extraction algorithm using run length method

- Ridge flow and local pixel analysis: It is a square based method to extract minutiae from Unthinned Binarized images which has 3x3 squares mask created around each pixel in a fingerprint image and the average of pixel are computed. If the average is less than 0.25 it is ridge termination minutiae and if the average is greater than 0.75 it is bifurcation minutiae.

4.1.2 **Thinned Binarized images with image post processing:** It is also known as Skeletonization-based minutiae extraction. Pre-processing techniques are applied. Thinning is the process of continuously eliminating the edge pixels of the image without changing the topological connection of the image pixels, and transforming the uneven fingerprints image into a striped centre line image whose line width is fixed to one pixel [4]. This includes two categories,

- Crossing Number Based: It is the most widely used minutiae extraction in this category. A skeleton image is used were the ridge flow pattern is eight-connected. The Fig 10 shows the local neighbourhood of each ridge pixel in the image is scanned using 3x3 window from which the minutiae are extracted. Then crossing value is calculated. The crossing properties can be used to classify a ridge pixel as a ending, bifurcation or non-minutiae point.

P4	P3	P2
P5	P	P1
P6	P7	P8

Fig 10

The Crossing number properties are show n in fig 11

Crossing Number	Property
0	Isolated point
1	Ridge ending point
2	Continuing ridge point
3	Bifurcation point
4	Crossing point

Fig 11

- Morphology Based: This technique is based on the mathematical morphology in which the image is pre-processed to reduce the difficulty in the post-processing. Morphological operators are used to remove spurs and bridges and then true minutiae are extracted with the help of morphological hit or miss transform.

4.1.3 **Minutiae extraction from a gray scale fingerprint images:** It is the current researched technique. This has lots of techniques to directly extract minutiae from gray scale to fingerprint without binarization and thinning. This extraction is due to the following reasons,

- Information might be lost during binarization process.
- Both Binarization and Thinning are time consuming process.
- A large number of spurious minutiae are introduced during Binarization and Thinning.
- Binarization does not clearly give clear information of latent images.

a) Ridge Line Following based minutiae extraction technique:

This method directly extracts the minutiae from gray scale by following the ridge flow lines with help of local orientation field.

b) Fuzzy based technique for minutiae extraction: The gray scale image has two distinct levels of gray pixels. One level is darker pixels which has rides. The other level is lighter pixels which has valleys and furrows. These two levels are monitored by fuzzy logic and fuzzy rules which are applied to extract minutia.

4.2 Other technologies

421 Core Point Detection based Fingerprint system: It is an algorithm based on orthogonal gradient magnitudes of orientation field of the fingerprint image for the core point deduction. An orientation field is estimated for input fingerprint image. Orientation field Θ(x,y) is represented as the ridge flow of the fingerprint of every location and is represented as [0; π]. For the fingerprint the Region of Interest (ROI) is computed. Segmentation of ROI from the fingerprint image is a common fingerprint pre-processing step within the verification process [5]. A binary mask with logical values is created by this segment.

422 CNN Algorithm: A Convolutional Neural Network (CNN) is a common technique applied to analyze visual imagery which is a deep neural network. It consists of an input and an output layers and also many hidden layers. Convolutional Neural Network algorithm is an algorithm which automatically finds feature information through the machine learning training and simplifies the tedious extraction process of manual or variety of other algorithms [6].

5. DATABASE

A structured collection of fingerprints mainly used for operational or evaluation recognition purposes are the fingerprint datasets. There are many datasets available for the Friction Ridge fingerprint recognition which is as follows

- Special Database 302: Nail to Nail (N2N) challenges for Fingerprint.
- Special Database 301: Nail to Nail (N2N) Fingerprint challenges Dry Run.
- Special Database 300: Rolled Images and Uncompressed Plain from fingerprint Cards.

The commonly used software's includes Biometric Evaluation Framework, C++ code for running biometric technology evaluations and NBIS a NIST Biometric Image Software which was formerly known as NFIS.

LITERATURE SURVEY

SN O	TITLE	AUTHOR	JOURNAL	OVERVIEW OF PAPER	METHODS USED	ABSTRACT THEAM	ACCURACY RESULT OBTAINED	FUTURE W
1	Secure Finger print Authe nticati on Using Deep learnin g and Minuti ae Verific ation	V. M. Praseetha , Saad Bayezee d, S. Vadivel	Journal of Intelligent System (IJSYS)	The identification and validation of individual were based on information system, which has passwords or cards for authentication. As these methods are less secure unique identifies are used for authentication. Fingerprint authentication has become a norm which has no vulnerability challenges. A novel experiment on fingerprint with two phases is performed in which the initial phase is pre-filtering of bad fingerprints and the next phase is fingerprint verification.	Google pre-trained Inception model with Convoluti onal Neural Networks architectur e,Google Inception –v3, Minutiae Verificatio n Algorithm [normaliza tion, Gabor Filter with Gaussian Function], KNN algorithm.	A deep convolution al neural network as a pre-verification filter to filter out latent or poor fingerprints. Deep learning helps the system to be accurate at detecting and false identificatio n can be reduced with training with test samples.	Using Tensorflow an accuracy of 94% is achieved. Tested the model with batch sizes 4,8,16 and 32, the best result is obtained in batch size 32	Qualcom is a technolog is going t get introduce with the feature of having sensors fo ultrasoun which ca pass through solid objects to capture informati from the fingertips
2	Autom atic Finger print Recog nition Syste ms: A Revie w	Prof. Shilpa P. Kodgire, Anju Mohan	Internation al Journal of Electronic s, Communi cation and Soft Computin g Science and	The study of various types of fingerprint technologies such as Minutiae Score matching , fingerprint verification system using artificial neural network, core	Minutia Score matching technique, Core point Detection , fingerprint verificatio n based on gabor , discrete	By considering all biometrics fingerprint recognition is considered to be the most prominent	Minutiae score matching methods were 65 -70 % matching, core point detection method about 90%,	There is a need of research i the existi pattern recognitio system an minutiae extraction to improv performa

			Engineering (IJECSCSE)	point Detection based fingerprint recognition systems, fingerprint verification based on Gabor filter , multi resolution feature subspace analysis for fingerprint recognition using PCA and fingerprint recognition using discrete wavelet transform .	wavelet transform and artificial neural network, multi resolution feature based subspace analysis	and reliable mechanism. Fingerprint recognition means matching the incoming fingerprint with stored fingerprints in the database which is said to be templates of every other users.	gabor filter method has 95%, artificial neural network has 92.5%, Principal component analysis has 96.3%, Discrete wavelet transform method as 95% and support vector machine method has 94.7%. Principal component analysis gave the most accurate result.	e.
3	Finger print Minutiae extraction using deep learning	Luke Nicholas Darlow, Benjamin Rosman	International Joint Conference on Biometrics (IJCB)	A convolutional neural network model called MENet which is Minutiae Extraction Network which has an automated supervised training procedure and post-preprocessing. Pattern recognition model is used for the	MENet Architecture, Softmax normalized probabilities with softmax normalization function	By using various existing minutiae extraction algorithms a voting scheme is implemented to construct the training data which is used to solve	The minutiae extraction model exhibits detection accuracy which serve to argument and to improve the existing fingerprint identification pipeline.	In future exploration on other aspects of fingerprint identification and comparison which are equally p as machine learning problems

				minutiae extraction.		robustness and portability.		
4	Recognition and classification of damaged fingerprint based on deep learning and fuzzy theory	Xinfeng Yang, Qiping Hu, Shuaihao Li	International Journal of Intelligent and Fuzzy systems	A deep learning fuzzy theory is used to classify damaged fingerprint. In this process a deep initially a improved fingerprint algorithm is used to refine the damaged fingerprint image which results in the data compression in of the fingerprint image, which is needed for the extraction of fingerprint image feature. Then a deep convolutional neural network is used to extract the features and fuzzy rough sets are used to reduce the extracted features. The reduced features are the inputs to the softmax classifier to get the damaged fingerprints. OPTA algorithm is used to refine the fingerprint	Improved OPTA fingerprint thinning algorithm, improved fuzzy discernibility matrix algorithm, fingerprint classification algorithm	In this paper a method of classification of broken fingerprints based on deep learning fuzzy theory is used. Pre-processing is done with the help of bifurcation point and the end point is broken to get the minutia. A fuzzy rough set is used to reduce the features which use softmax classifier to classify the damaged fingerprint image. After pre-processing OPTA algorithm is used to refine the damaged fingerprint	The methods used perform better than other algorithms in which the recognition rate is 97.1%.	In future improved method fo the classifica n and identifica n of fingerprin can be do for better recognitio rate.

				data and connect the disconnection and remove the noise. Classification accuracy can be improved with the help of softmax classifier to reduce the features.		image, which helps to effectively extract fingerprint image by deep convolution al network.		
5	Finger print ROI Segme ntation Based on Deep Learni ng	Branka Stojanovi c, Oge Marques, Aleksand ar Neskovic , Snezana Puzovic	Internation al Telecomm unication Union Journal	There are mainly four main steps namely pre-processing, samples creation and processing. The CNN has tow architecture AlexNet Architecture use for object recognition and LeNet architecture for handwritten digits recognition.	ConvolutioalNerual Network Algorithm with AlexNet architectur e and LetNet architectur e	A novel method for Fingerprint ROI segmentatio n using Deep Learning technique with the help of Convolution al Neural Networks.	The method is significantly better across all methods regarding the fingerprint images with the noise.	The meth unlike Fourier coefficien based wh can be applied to real latent images.
6	A Robust Damag ed FInger print Identif ication Algorit hm Based on Deep Learni ng	Wang Yani, Wu Zhendon g, Zhang Jianwu, Chen Hongli	IEEE Advanced Informatio n Managem ent Communi cates, Electronic and Automatio n Control Conferenc e (IMCEC)	The fingerprint recognition model based on deep learning put forward a robust damaged fingerprint identification algorithm which initially has a central block fingerprint which has a Poincare formula and Convolutional Neural Network	Convoluti onal Neural Network, Poincare formula, activation function with sigmoid function, Kernel Principal Componen t Analysis (KPCA),	Robust damaged fingerprint recognition algorithm based on Convolution al Neural Network of deep learning is used which has high resistance to abnormal degeneratio	Fingerprint recognition based on deep learning has higher robustness with 94.73% recognition rate.	Improved structure parameter of CNN network which obtain hig recognitio rate and shorter training time especially for blurre fingerprin

				for the image recognition, it has multiple features maps with different weight vectors, obtaining a variety of different features at the same location.	feature Points Matching	n and recognition is simpler in comparing with feature points matching algorithm.		
7	Patch Based Latent Finger print matchi ng using deep learnin g	Jude Ezeobiej esi, Bir Bhanu	Internation al Conferenc e on Image Processing (ICIP)	A new system of patch based latent fingerprint matching using deep neural networks with an improvement on the previous fingerprint matching results. An optimal patch representation and patch similarity without relying on hand crafted features.	Represent ation learning network(R LN), Similarity learnig Network(S LN), Minutiae matching	An approach for matching latent to rolled fingerprints using similarity of learned representati ons of patches and the minutiae on the correlated patches.	Experiment al results show a rank 1 identificatio n rate of 81.35%.	A deep learning approach for minut extraction and exploring the performa e on a lar fingerprin database with mixe images resolution
8	A Novel Finger print Classif ication Metho d Based on Deep Learni ng	Ruxin Wang, congying Han, Tiande Guo	Internation al Conferenc e on Pattern Recognitio n (ICPR)	A Neural Network structure Stacked sparse autoencoder (SAE) which has three hidden layers used to learn a low-dimensional representation which are features of the input data.	Stacked sparse autoencod er (SAE) neural network, softmax regression, fuzzy classificati on	Samples classificatio n is difficult because single feature has weak robustness for fingerprints with poor quality and the ridge structure of some samples	The highest accuracy result is obtained with the experimenta l result of 99% with the method used.	Multiple features a classifiers can be considere for classifica n task, an classifica n based original images ca be done.

						with a strong similarity to another type.		
9	Contactless Fingerprint Recognition and fingerprint spoof mitigation using CNN	D.Sindhuja R. Jemina Priyadarsini	International Journal of Recent Technology and Engineering (IJRTE)	A CNN based model is used for the identification of contact less fingerprint recognition. A model is tested which is achieved more accurate identification.	CNN algorithm, CANNY algorithm, Spoofing	A CNN framework for recognizing contactless fingerprint images. Fingerprint minutiae and particular ridge map region to train a CNN is done.	Good results with greater accuracy proving huge security. Threshold value becomes one with maximum accuracy.	Improved identification accurac by incorporating greater training s as well a strategies
10	Touch less fingerprint Biometrics: A survey on 2D and 3D Technologies	RUggero Donida Labati, Angelo Geoverse, Vincenzo Piuri, Fabio Scotti	International journal on Internet Technology	Recognition methods can be divided into some common steps, Acquisition, computation, of a touch –equivalent image, feature extraction and matching.	Parametric algorithm , non-parametric algorithm	To increase the usability, acceptability and accuracy of the fingerprint recognition technology touch less system can be used.	These results predict a touch less based fingerprint recognition technique with the two-dimensional and three-dimensional classification with more accuracy.	Rather tha two-dimensio and three-dimensio classifica n some other classifica n technique can be us for improved accuracy.

6. ADVANTAGES AND DISADVANTAGES

6.1 ADVANTAGES

The advantages of Fingerprint recognition technology are as follows,

- Security: There is a big improvement on passwords and identity cards but still they can be hacked. Fingerprints are harder to make fake .
- Ease of use: it is very easy for the users which don't require struggling to remember passwords or being forgotten to take the ID.
- Non-transferable: fingerprints are non-transferable which cannot be shared to others.
- Accountability: fingerprint provides vast level of accountability at work. Certain condition in which incidents occur this can be used as evidence.
- Cost Effective: As a vast improvement in the technology fingerprint recognition is cost effective.

6.2 DISADVANTAGES

The following are the disadvantages of fingerprint recognition system. They are as follows,

- System Failures: There is a chance for some technical failures and limitations as other electronic identification system.
- Cost: Fingerprint recognition systems are cost effective that ever, but for smaller organizations the cost for the implementation and maintenance can become a barrier.
- Exclusions: fingerprints remain relatively stable over a life time of a person. There are sections of population which are excluded with the use of this system. For example, traditional people with the manual work will find difficult to register worn prints to the system or those who don't have fingers they are excluded.

7. CONCLUSION

High uniqueness and ease of capturing makes fingerprint technology as more frequently used biometric technology. Fingerprints have been one of the most reliable methods used in forensics for human recognition [7]. The main focus of this paper is the various fingerprint recognition technologies and their techniques which includes neural networks, Minutiae extraction and so on. The various attributes of fingerprint with its variety features has also been focused. In the literature there are also methods and algorithms for the feature extraction and matching strategies. In future there is a need for research in existing pattern recognition systems which has matching strategies for the improved performance of extraction techniques.

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