Classification and Recognition of Noisy Fingerprints Using Quaternion Matrix and Multi-Layer Perceptron

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Abstract:

This research primarily focuses on fingerprint identification system. Fingerprint identification is a biometric authentication system that uses a computer database of fingerprint records to confirm an individual's identity. Here for training and testing purpose we have used custom dataset which comprises of several scanned fingerprint images. To delve deeper into this area, we have referred to previous researches intending to obtain the best results. To enhance the fingerprint image and extricate the required features here we have applied the Quaternion Kalman filter. This filter is based upon the conception of hyper-complex numbers. In our study we have used the loss function of quaternion filter for obtaining the best outcomes. Subsequently, in order to classify the extracted features Multilayer Perceptron (MLP) classification approach is suggested in research. MLP is an Artificial Neural Network (ANN) which is used to solve supervised learning problems. In the suggested methodology, MLP is implemented for classifying the enhanced features of the original fingerprint image and the recognized one. Thereafter, Fingerprint matching is performed using quaternion algorithm which is based upon neural networks. It helps to get better visualization of an image. Proposed methodology leads us towards the finest results.

Keywords – Fingerprint Recognition, quaternion, MLP, PCA
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I. Introduction:

A biometric system can be defined as a system that identifies an individual based on biometric features such as iris, face, fingerprint using a mathematical algorithm and biometric data. It has become very popular in the last few decades. In the present time it is used in lots of authentication process, whether it is an iris recognition, face recognition or etc. Fingerprint recognition biometric system is the most popular one which has various use cases in the present era. It is the most common biological trait that is used in different identification, recognition, and authentication processes. Basically, fingerprint recognition biometric system works upon two main processes termed as enlistment of fingerprint images and the verification process[2].

Fig 1: Representation of the Dataset using Plot Library

In the enlistment process the fingerprint images are collected by using some scanners [as shown in **Figure 1**] and in verification process software matches the fingerprint image with the database and gave allowance for authentication. Fingerprint of a person is an impression which is made up by friction ridges of a finger. Biometric simply works upon the unique patterns and persistence. The algorithms working behind a fingerprint detection system are primarily focused upon the feature extraction of fingerprint image[3,2]. The key feature of a fingerprint is "Minutiae". Minutiae specifically comprises of different fingerprint structures like termination, bifurcation, delta, crossover etc. The histogram obtained from the dataset is shown in [**Fig 2**].

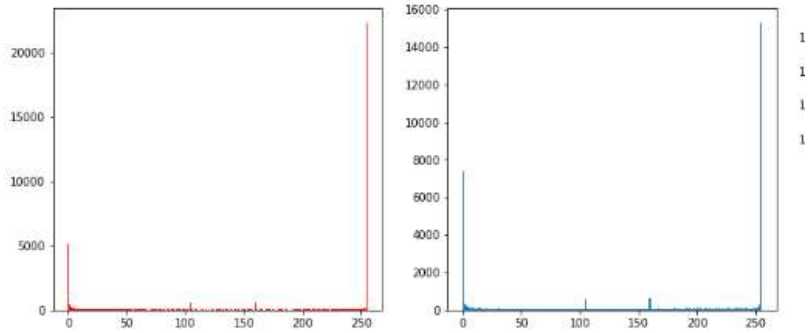

Fig 2: Histogram of axes extracted using Plot Library

In the research we are proposing a methodology which helps to enhance the accuracy of fingerprint recognition biometric system. For this purpose, we have utilized a custom dataset of fingerprint images. In our model, Minutiae feature extraction is performed by using Quaternion Kalman Filter[8]. This filter helps to track within the 3D spaces which gave better visualization of a fingerprint image. Quaternions are Hyper Complex numbers. Thereafter to implement classification approach on the extracted features we have utilized Multi-layer Perceptron (MLP) Classification algorithm. MLP Classifier works upon the fundamental of Neural Network[5]. It uses back propagation method in order to train the model. It is very efficient approach for non-linear models as well as real time models. Subsequently at final fingerprint matching accomplished with the help of Quaternion algorithm.

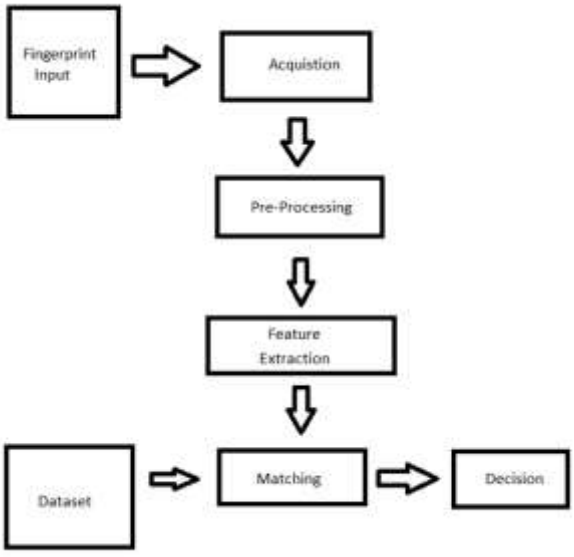

Fig 3: Flow Chart of Fingerprint Recognition System

The MLP [Multi Level Perceptron] giving best results when 8 hidden layers are used. MLP begins with Input layers ends to the Output Layer. The transition from the input to output layers bring the precision which is much needed in this model. 8 classification models are used to determine the accuracy and the best of them were chosen for the classification. It is chosen as the stage-6 of the Classification Model [**Fig 4**] depicts the stage process of Fingerprint Classification.

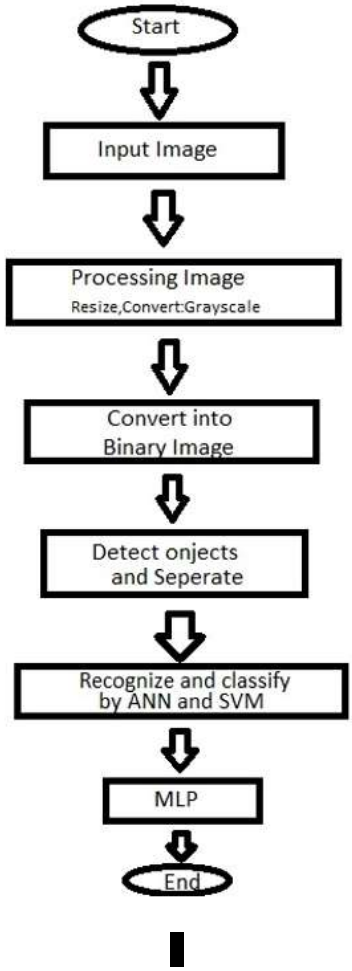

Fig 4: - Flow Chart of Fingerprint Classification

The above theory states about the research made in the paper. All the steps are explained in a proper way in the Methodology Section later in the paper.

II. Literature Review:

Rodrigo Frasetto Nogueira et al. [1]used four fingerprint recognition models for liveness detection in their study, that are CNN-VGG, CNN-Alexnet, CNN-Random, LBP. CNN-VGG (Visual Geometry Group) is the Deep convolutional neural network in which multiple layers resides for training the model. It is used for large scale image recognition system. They used this Deep network for enhancing the accuracy and gaining best results [12]. The algorithm used to train CNN-VGG is the Stochastic Gradient Descent(SGD) with a batch size of 5 and a fixed learning rate of 10^-6. After that they have utilized the CNN-Alexnet which is very similar to model Alexnet i.e. already trained on ILSVRC-2012 database [48]. Whereas, CNN-Random model is utilized for making such approach that is different for each database. It uses grid search algorithm for execution. Further in study they have used LBP (Local Binary Patterns) model which is very famous for Fingerprint Liveness detection and recognition. For the implementation part, they used different approaches and achieved the best accuracy

rating of 95.51% for the CNN-VGG model. They have suggested that Database augmentation part is the most important for enhancing the accuracy of the model.

Lucas Nicholas Darlow et al. [2] have proposed MeNET - Minutiae Extraction Network for fingerprint recognition and feature extraction. In their research they've studied various minutiae detection algorithms. They described minutiae asridge ends and ridge bifurcation, which are the features considered for implementing the Deep learning model. They have provided a model that could be verybeneficial for data-drivenstrategies and has a deeper structurewithin side thesubject of Neural Networks.MeNET is a CNN model built from 5 convolutional layers which is further followed by 2 fully connected dense layers and 1 softmax output layer.The main use case of this model is to extract minutiae features of a fingerprint image.After making the CNN-MeNET model they have performed Binary performance evaluation which is further continued by Qualitative Assessment. The success rate of the whole implemented model is 80%. In this research they have utilized the advantages of all the previous researches and worked upon the large scale of data.

Chiroma et al.[3] Addressed a CNN model to improve the performance of AFRS (Automatic Fingerprint Recognition System). In their research they have studied various DL (Deep Learning) models with the view to understand the Fingerprint Detection Biometric Systems. Among all the suggested models they have preferred Deep Learning model for end to end training and feature extraction process which is implemented with the help of dense convolutional neural network. The selected features for model building are Arc, Left Loop, Tented Arc, Left Loopand Whorl… these all are the parts of minutiae. In AFRS they have implemented five major steps. Firstly, image acquisition performed for obtaining data. Thereafter pre-processing is implemented for clearing the noise of data and getting normalized one, which is further followed by feature extraction in which dense convolutional networks used. Subsequently Matching and classification is performed by utilizing Principle component analysis (PCA) and Support Vector Machine (SVM) classifier. They have suggested the model for improving the accuracy of network and enhancing the performance of AFRS.

Mouad .M.H.Ali et al. [4] have reviewed various researches and proposed an idea based upon that which is implemented in four stages. The first step is the acquisition stage in which images are collected by online and offline methods.In the web fingerprint identity, the optical fingerprint reader is used to capture the photograph of fingerprint (NIFT, FVC, THU database).The offline fingerprint identity is receivedvia way of means of ink within side thevicinity of finger after whichpositioned a sheet of white paper at the fingerprint and in the end scans the paper to get a virtualphotograph.After that the pre-processing part occurs in which the cleaning of image data is performed bythe various approaches that are Normalization of image, Orientation, Image estimation followed by Gabor filtration. Subsequently Feature extraction is performed, in which minutiaeextraction algorithm is utilized, minutiae extraction algorithms helps to find out the minutiae points on the fingerprint. Minutiae points are the locations on the fingerprint on which ridges become discontinuous like bifurcation, termination, delta etc. The final stage is the comparison stage in which fingerprints in database are compared by matching the features which are extracted previously. Matching the features is done by using three approaches the first one is the Classification method, in this approach the KNN classifier is utilized for assigning the classes to each fingerprint in the database. Further two methods are Hierarchal approach and Coding. Hierarchal method had been used for enhancing the accuracy whereas coding approach helps to search the matching feature in the entire database.

Anil K. Jain et al. [5] have researched on the fingerprint detection of young children's. In their study they have focused upon Dalton's statement that a new born baby can be identified using fingerprint. Fingerprint can be an ink expression or the web scanned. They saw it as a major problem that young children

of today's age have no identity, so they developed a solution that can read the fingerprint of a new born child as young as 6 hours. They used different fingerprint recognition applications in their study. First, they captured the child's longitudinal fingerprint through the use of fingerprint readers. After that, they created a database using the data collection protocol, which is further followed by fingerprint recognition. The main problem they faced during the process was the time lapse between fingerprint collection and fingerprint image related query. So, for the verification process they used performance evaluation metrics where two parameters are measured, the first is the true success rate and the second is the false success rate. Using both parameters, they determine the rank that will be used for the verification process. The ranking is evaluated at the time of the search query raised. Through this whole approach, they wanted to give each little child an identity, so that no child is left without identification in the country.

Sharat Chikkerur et al.[6]Have proposed an algorithm based on unified frequency domain analysis with the aim to enhance and extract the global features which includes the locations of ridge orientation map, core and delta from the fingerprint images. Intending to extract the minutiae points from fingerprint image they had suggested a different novel algorithm that basically uses a method based on chain coded contour ridge. The efficiency of the feature extraction is calculated by analysing the extracted minutiae points from the original image. In this work the performance of the algorithm is evaluated on a subset of FVC2002 DBI database. To enhance the quality of the fingerprint images here the suggested algorithm takes the advantage of the information obtained from the Fourier domain analysis of the fingerprint images. In their study they have considered two parameters 'Sensitivity' and 'Specificity' to evaluate the suggested algorithm. The scalability of the fingerprint recognition system entirely relies on the quality of extracted minutiae. The above mentioned terms 'Sensitivity' and 'Specificity' help them to analyse the true minutiae and discard the false minutiae. Means values of 'Sensitivity' and 'Specificity' that are obtained on a subset of FVC2002 DBI database are 79.40% and 85.29%.For their proposed algorithm they specifically recommended to use Heuristic rules.

Raman deep Kaur et al.[7]have implemented different steps in order to build an effective minutiae extractor. After the implementation of these various steps which includes normalization, orientation estimation, ridge segmentation and smoothing, thinning, minutiae post processing and region of interest, a final output image is obtained which comprises information regarding the minutiae points. Thereafter extracting the minutiae points from the fingerprint images, the bifurcation and termination points are calculated by using the concept of cross numbers. This is further followed by the evaluation of the angle of minutiae point which is calculated in the correspondence of the neighbouring pixels. With a view to extract the features of fingerprints they have introduced a new smoothing algorithm. The algorithm proposed in this study is tested on the dataset of 102 images. The suggested approach is used to analyse the various parameters of the images such as the number of directions in the orientation field. To evaluate the ratings of the proposed algorithm various criteria have been utilized which includes-genuine acceptance rate, false rejection rate and false acceptance rate.

Zhixin Shi et al.[8]have addressed a feature extraction algorithm based on the chaincode representation of fingerprint ridge contours. Chaincode representation is basically used to enhance the quality of the binary images. The representation facilitates image quality enhancement and the recognition of fine minutiae feature points. The idea of representing the minutiae points in terms of chaincode representation originated from chaincode tracing. Most of the minutiae extraction algorithms are based on thinning but it are not preferable everytime as these methods are sensitive to noise. With the aim to measure the performance of the

enhancement algorithm they have used a parameter of the extracted minutiae named as Good Index (GI).The chaincode based minutiae extraction algorithm is implemented on both the original and enhanced images after the application of adaptive binarization. In order to evaluate their suggested algorithm they had chosen some sample images from the FVC2004 dataset. The proposed approach comparability can be explained in the terms that it does well in two categories among three. Here the reason for the false minutiae is either the binarization of the local area or the broken ridges.

NALINI K. RATHA et al.[9]have introduced a feature extraction approach for fingerprint images based on the flow of direction of ridges. Intending to locate the ridges accurately they proposed a waveform projection based ridge segmentation algorithm. Ridge segmentation is considered to be an ideal model for ridges. After the implementation of this above-mentioned algorithm we obtained a thinned ridge image that is further smoothed by using morphological operators. Subsequently, based on the number of crossing the minutiae are extracted from the thinned ridges and spurious minutiae are discarded by the implementation of a post processing step. This suggested algorithm is tested with 100 fingerprint images of different qualities. The performance of mentioned algorithm is evaluated by comparing recognized minutiae with the original set of minutiae detected by the human expert from the same fingerprint image.To measure the efficiency of the proposed algorithm the good index named parameter of the minutiae is taken into consideration. Good index is calculated to substantiate their claim of durability.

Xin GAO et al.[10]in their work have proposed a novel approach of feature extraction for gray scale images based on the Gabor phase field. Gabor filter is a linear filter that is primarily used for texture analysis. It detects specific frequency data in the image which is specified in a particular direction in common confined region around a specific point of analysis. Gabor filter works upon reference points which are defined by harmonic function. It is used to enhance the intensity of the ridges and mitigates the valleys. Gabor phase based minutiae extraction is a sparse model that has various use cases such as pattern recognition, image recognition etc. The accuracy of this approach is evaluated on FVC 2004 database set. With a view to calculate the performance of the algorithm here they have consider the two parameters termed as true positive rate (recall) and true predictive value (precision) to the compare the detected minutiae with the manually extracted minutiae. Thereafter the algorithm efficiency was tested on the fingerprint matching and results were expressed as equal error rate(EER).The experiments have depicted that the performance of GPME is better than any other used algorithms like global structure based algorithm ,the GrowFuse method and the star-structure method.

The segmentation algorithm is used for classifying Text with the help of Multi-Level Perceptron[11]. 8 layers MLP, is used for the best results. The results of the segmentation project were passed to the input layer of MLP and then the results were passed to the hidden layer and later to the output layer. The Researcher has focused mostly on the segmentation task, so self tuning MLP classifier is used to optimize the parameters. The researchers also have focused on the binary SVM[12]. The final result of this research landed up to 93.48%, which is a great number. The results were improved by increasing the training samples as mentioned by the Researcher.

The Researcher Allan Pinkus has focusedmostly on the use of MLP in the neural Networks. Research has been classified on the basis of the Hidden Layers. Some theorems are stated from the previous researches and eventually proved the results shows better precision when it lands up with more than one Hidden Layer[13]. Activation Function is used as criteria to guide the theories and results to the fact that more than one Hidden Layers gives better results than single Hidden Layer. Use of these layers

widely depends upon the use-case. The author have given a light over the calculations and derived some new relations that proves the fact theory of approximation can be incorporated in Neural Networks using Multi Level Perceptron.

The researcher has focused completely on the MLP architecture[14]. Dealing with the evolution with Delta rule Learning. The model shows great results when "Tanh-Tanh" was usedas a pair of A.C[Activation Functions] which was further used in both Input and Output Layers. The concept was based on Calculation of Error Value completely on the basis of Iterations. The result of this Research proves that there was a minute change in the accuracy when the number of Iterations were increased 5 times and number of hidden Neurons were increased by 8 times. The best result was shown by Bi-Polar S at 100^{th} Iterations and Tanh at 500^{th} Iteration. The above Results were shown as different Activation Functions and this research was just a comparison between them.

III. Methodology:

- **Image acquisition:**

Training and testing of model requires a database for the processing purpose. Intending to achieve the goal we require the database which comprises images of fingerprint [21]. The image acquisition process is performed by open source field collection. Background is scrapped using Open-Cv by creating a map around the print. This map results in the generation of clear image with white background.

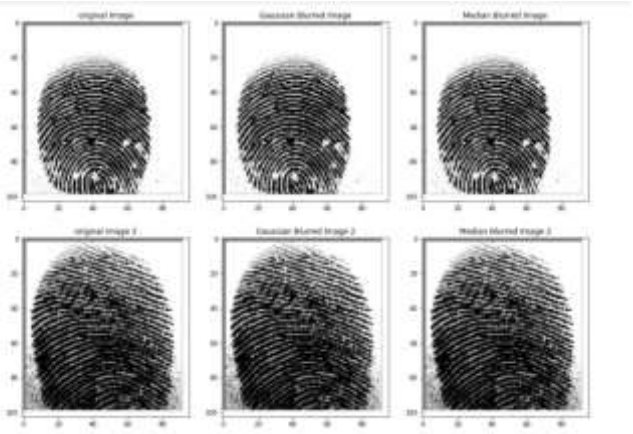

Fig 5: - Image Acquisition & Enhancement of the Database

The Gaussian and Median blurred results are generated for the further feature extraction as discussed in the Introduction Section. Original Image is used for Fingerprint Recognition and Gaussian image will be used for the extraction of features. This creates the multiple performance model in a single model. For Feature Extraction, edge detection is must Median Blurred Image is used for the same.

- **Image Enhancement:**

Image enhancement is the technique which helps in improving the quality of the raw image so that image would be clearer and better for further processing. This process is very important in the terms of getting suitable results [27]. Enhancement upgrades the visual standards of an image. In Biometric system this technique is used to improve the visibility of any feature of image by reducing the noise factor of image. Image enhancement illuminates the image, sharpen the features and balance the rate of divergence. In our model image enhancement is used to perform three major tasks that are Image smoothening, Image thresholding and Edge detection.

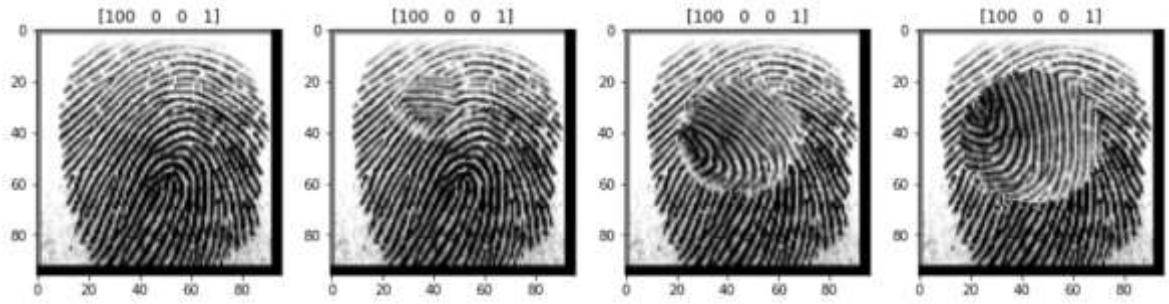

Fig 6: - Gray Scale Finger Print Conversion

To enhance the fingerprint image initially we have performed Gaussian and Median blur operation. Gaussian blur operation is a Gaussian function based image blurring technique that is basically used to reduce the noise in the image. Median blur operation is an averaging method in which we replace the central element of image by the median of all pixels present in image. It is used as a nonlinear noise removal filtering technique. Here Robert filter is used to detect edges in fingerprint images through 2-D spatial gradient measurement on an image.

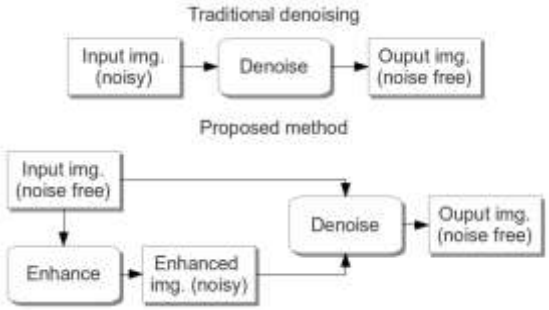

Fig 7: - Flow Chart of Noise Reduction

After the reduction of noise, the dataset is ready to meet the Extraction and Recognition Phase. First the Fingerprint Recognition will take place and later the results will be complimented by the Feature Extraction of these Fingerprints.

- **Fingerprint Recognition:**
  - **Quaternion Kalman Filter**: - Recognition is carried out using Quaternion Kalman Filter. The work of the filter is to produce estimations for the hidden variables. This model makes the estimations more accurate and less faulty. Filter uses data from the past records and append furtherfor the best results [14]. While dealing with recognition phase the estimations play an important role to make the model handy and easy to implement.

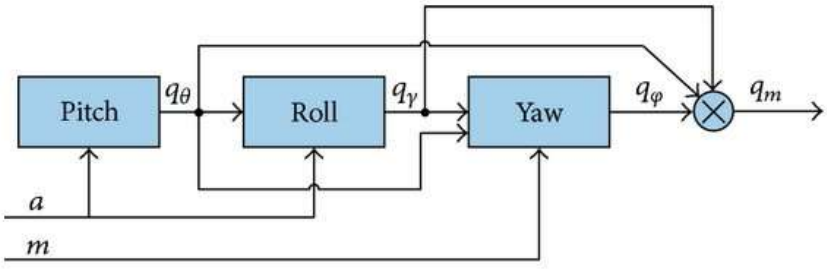

Fig 8: - Flow chart of Quaternion Kalman Filter

As per the [Fig 8], the relations between Pitch, Roll, Yaw is highly complex. The Kalman model earlier was only used for Palmprint Recognition. The model was made compatible as per the requirements. The basic relations never changed. The concepts are same only the implementations are made complex. Pitch, Roll, Yaw are interconnected with a tight entity[41]. The result q_m is the final result

adopted for the recognition process to take place.

The quaternion adopted is based on the concept where only 4 parameters are adopted, one real part and three imaginary parts.

$$Z = p + qi + rj + sk \quad [1]$$

Multiplying the result with the conjugate will result in the formation of result [2] shown Below: -

$$Z.Z^* = p^2 + q^2 + r^2 + s^2 \quad [2]$$

By simplifying the results, the distance between the 2 quaternions are taken as realtion [3].

$$D(a,b) = |a - b| \quad [3]$$

- **Fingerprint Classification**: -
  - **Feature Extraction: -**Feature extraction is the process of reducing image dimensionality by encapsulating the effective part of a fingerprint image. To extract the required and non-redundant feature from the image here we implemented Kalman filter along with the quaternion [26].Kalman Filter is standard tool in linear phase space estimation. In the research we used above mention tool to figure out unseen coordinates of fingerprint image.Quaternions are three dimensional vectors which work upon on the concept of hyper complex numbers. It has one scalar and one vector part. When the scalar part of the quaternion becomes zero then the quaternion is called as the pure quaternion. Quaternions are used to study the visualization of 3-D rotation of an image. Quaternions basically finds there applications in computer graphics, game development, robotics etc.

    Once the extraction is done, the results are further saved in Numpy files, CSV files and will be used for the later purpose[18]. We have combined Kalman filter with quaternion to solve the 3-D attitude estimation problems. It is easier to extract features using quaternion Kalman filter because quaternion gives better visualization and Kalman extract features more precisely.After successful implementation of quaternion Kalman filter we obtained features in the form of minutiae. In a fingerprint the dark lines are edges and the brighten area appears as trough. Minutiae points are the position at where edges appear to be discontinuous. There exist different types of minutiae points like termination, bifurcations, dots, islands, lakes, spurs, bridges, delta and crossovers. A point where the edge ends is known tobe termination on the other side the point where the edge branches/bifurcates is said to be ridge bifurcations. Subsequently, we further classify the extracted features.

  - **Constructing the Quaternion Matrix:** - In the same way that complex numbers can be represented as matrices, quaternion's can be represented in the same way. Matrix addition and multiplication can be expressed as quaternion addition and multiplication using at least two different representations. There are two approaches: one employs [2][2] complex matrices, the other [4][4] real matrices**.**

$$\begin{bmatrix} a+bi & c+di \\ -c+di & a-bi \end{bmatrix}. \quad [4]$$

For the Classification Process, the features are represented in such matrix and saved for the classification process.

- **Recognition:** It is the final stage of model which decides the authenticity of user on behalf of fingerprint

matching. In our suggested approach, fingerprint matching is performed by using Quaternion algorithm. On the basis of similarities in the features it makes decision that whether the user is authorized or not. We have used this approach because it is quick as compare to similar algorithms and it is very efficient for getting the best outcomes.

Acquiring features and matching them to database templates are two separate processes. To put it another way, the matching stage involves determining the degree of similarity between a user-supplied test image and a database-stored training image (the template which created at the time of enrolment).

Hierarchical, classification, and coding approaches can all be used for matching. There is an increase in matching speed but a decrease in precision when using a hierarchical approach. Each biometric in a database is assigned a class by classification approaches. KNN classifier [15] is one of many classification methods. Database-searching methods that use only one matching function. Hybrid fingerprint matcher proposed by Arun Ross and colleagues (16) uses both ridge strengths and a small set of minutiae points.

A study on hybrid fingerprint matching methods was presented by Johg Ku Kum et. al. [17]. Combining minute matching with image-based fingerprint verification methods, they match fingerprints by using cross (diamond and dispersed) and square shapes as the basis for matching.Matching algorithm used by Swapnali Mahadik et al.[18] is Alignment Based Minutiae Matching. In order to perform the matching stage, the images are subjected to translation, rotation, and scaling. By integrating three fingerprint matching algorithms, Hough transform, string distance and 2D dynamic programming-based matching using the logistic regression method, Anil Jain et. al. [19] performed their matching stage.In this work, the matching is done using Ridge Based using the Hough transform method, similar to Nilcau Marana and Jain [20].

Layer	Layer Number	Param
Input Layer	[3]	0
Conv2D	[0]	320
MaxPooling2D	[0]	0
Conv2D	[1]	18496
MaxPooling2D	[1]	0
Conv2D	[2]	73856
MaxPooling2D	[2]	0

Fig 9: - Layers used in Feature Recognition

- **Classification**:

Classification of features is performed by using MLP (Multi-Layer Perceptron). MLP is a deep learning model where there exist several layers between input and output layer in the form of directed graph. MLP primarily used in solving the supervised learning problems like image recognition, speech recognition etc [46]. In the study we have utilized MLP Classifier to figure out that the image belongs to which hand. It is a neural networks based classifier which primarily works on the concept of Back propagation. In the implementation of classifier, features are treated with 8 layer perceptron after removing the last layer of the model. The main advantage of using MLP Classifier is that it has the capability of working on non-linear function with best results because it uses multiple hidden layers for processing except the input and output layer. Subsequently the final stage of fingerprint matching performed after the classification.

The Classification is done by the concept of Feature Extraction. The features were extracted from the dataset. Results of a major step [Adaptive Thresholding] are shown below which constitutes the major step of Feature Extraction. The results can be seen in **[Fig 10].**

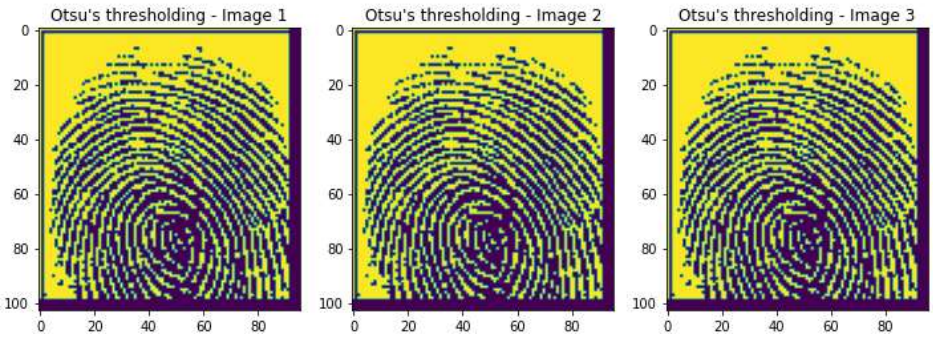

Fig 10: - Results of Otsu's Thresholding

Ridge Detection is also an important task, as most of the features are present there. To extract them a proper Tensorflow CNN, is constructed to focus only on these patches. The ridgesare easily to find, its main location are categorized by Hessian Matrix. Eigen Values are stored in a matrix form which are further plotted using Plot Function in python. The Ridge Detection are shown below in **[Fig 11].**

Fig 11: - Ridge Detection on Random images from Dataset

The last result of the Extraction phase is the Convulation Images that vary in the form [Robert, Sobel, Prewit]. The mask detects edges whenever the pixel intensities abruptly change. Because the edge is defined as a change in pixel intensity, it can be calculated using differentiation. This mask is derived from the Prewitt one. Prewitt-result mask's is represented graphically by a graph in which the edges are represented by the local maxima or minima.For example, we can adjust the mask coefficients in the Sobel operator to suit our needs as long as they adhere to the properties of derivative masks. The results can be seen in **[Fig 12].**

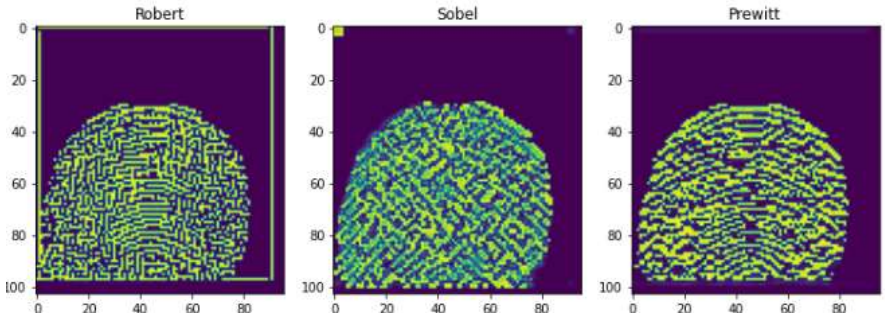

Fig 12: - Convulation Images of the Dataset

The final results of the Feature Extraction, is shown below **[Fig 13].** Fingerprint uniqueness is determined solely by the characteristics and relationships of the local ridges. a fingerprint is composed of an alternate pattern of ridges and valleys, each flowing in a localised, predictable direction.

Layer	Layer Number	Param

Conv2D	[5]	34944
MaxPooling2D	[3]	0
BatchNormalization	[8]	384
Conv2D	[6]	2973952
MaxPooling2D	[4]	0
BatchNormalization	[9]	1024
Conv2D	[7]	885120
BatchNormalization	[10]	1536
Conv2D	[8]	1327488
BatchNormalization	[11]	1536
Conv2D	[9]	884992
MaxPooling2D	[5]	0
BatchNormalization	[12]	1024
Flatten	[1]	0
Dense	[4]	1052672
Dropout	[3]	0
BatchNormalization	[13]	16384
Dense	[5]	16781312

5807

Fig 13: - Layers used in Feature Classification

IV. Results

The results of the research were quite interesting. The 2 phases of the model worked well. Especially the Recognition phase showed high accuracy on the dataset. The dataset used was 30 classes, with total images 30 * 15 images, making it 450 images. The images are first converted into a Numpy format. These numpy coordinates were further used in Classification and Recognition. If we divide the results between Recognition and Classification.

- **Fingerprint Recognition: -**

The accuracy on training set of FER_2013[49] is 98.97 using the layers shown in table 9. The model was trained on 50 epochs. Train and test split were focused on 20% for wide range of training data.

- **Fingerprint Classification: -**

Ridge bifurcation and ridge ending are the two most prominent local ridge characteristics. It is defined as the point where a ridge abruptly comes to an end. To define a ridge bifurcation, we must look at where it splits in two. The term "minutiae" refers to all of these small details.

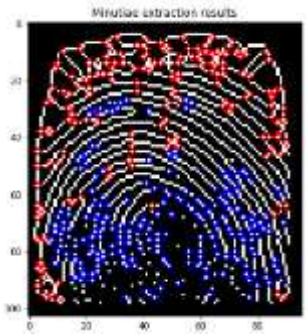

Fig 14: - Minutiae Extraction of the Fingerprint

After extraction the accuracy on FER_2013[49] was seen as 93.86% which is not bad while classification of robust data.

V. Conclusion

More than a century of research has gone into fingerprint authentication. The only reason its use has become so widespread and mainstream in the last few decades is because of technological advancements of fingerprint

recognition systems that are automated. Because of the growing need to reduce the number of errors and failures insystems that automatically identify fingerprints improving their safety has led to the discovery of numerous intriguing and a wide range of unique research possibilities computer vision, and image processing sensors, statistical modelling, and cryptography.

Fingerprints have been found, according to our preliminary investigation. Proven to be one of the best biometrics, if not the best, and there is still a lot of room for improvement. Despite this, there are still concerns about things like fingerprint authentication at a bank. Large-scale identification over long distances and in real time Fingerprint-based security is a challenge because there are so many records.

Templates for revocable fingerprints that maintain accuracy and Fingerprints can be proven to be unique through scientific research. Most likely, they will continue to be major obstacles for the foreseeable future.

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