EE 516:Introduction to Digital Signal Processing: Final Project Report
Fingerprint Image Restoration and Classification

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Introduction:

This project aims at improving the classification of blurry fingerprint Images using several image restoration and enhancement techniques predominantly in the frequency domain. Fingerprints are classified based on gender(Male or Female). Fingerprints are composed of ridges and furrows and are one of the unique traits used for identification of an individual. There are some significant differences between male and female fingerprints. Female fingerprints exhibit higher ridge densities than male fingerprints. This means that female fingerprints have narrower ridges as compared to male fingerprints. However with increasing age people exhibit a decrease in the ridge density.

Here are some sample fingerprint images based on gender

Male

Female

Dataset

The Dataset (SOCOFing) is a biometric fingerprint database designed for academic research purposes. It is made up of 6,000 fingerprint images labelled by gender(Male or Female), finger(Index,middle,thumb,ring,little) and hand(right or left). However for this project, we will be doing a binary classification of fingerprints based on gender

The dataset has got a usability rating of 7.5 on a scale of 10.

Approach

1. Data Preparation

In real world fingerprint images are generally prone to various kinds of degradation. For example, fingerprint image samples taken from a crime scene are generally very blurry and noisy and are not very clean. To account for this, the images in our dataset was degraded in two different ways.

- Images were degraded without noise by applying isotropic gaussian blur with a random sigma value.
- Images were then degraded by adding noise to the previously blurred images using the random gaussian kernel.

Image degradation without noise

As mentioned above, Images were initially degraded without noise using a gaussian kernel of a random sigma value(standard deviation). A random kernel size can also be chosen but that increases complexity of the point spread function estimation from a linear to polynomial as nested loops are required. These kinds of blur generally occur when the optic system of the camera module is faulty. Since noise is not added to the images, in this case, blur modeling, point spread estimation and deconvolution becomes easier.

Gaussian function is a normal distribution function. Here’s the formula for a gaussian function used for blur modeling.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Here's an example of a fingerprint before and after degradation.

Before Degradation After Degradation

Image degradation with noise

Recovering the images that are degraded are fairly easy in the absence of noise. However, in a real world scenario, images get corrupted with noise and there are several sources that add noise to an image which makes image restoration difficult. Two of the most common reasons for noise is poor lighting and temperature. This kind of noise can again be generally modeled using a Gaussian function.

Here's an example of a fingerprint before and after degradation(blurring and adding noise)

Before Degradation After Degradation

2. Bare classification of degraded images and prediction

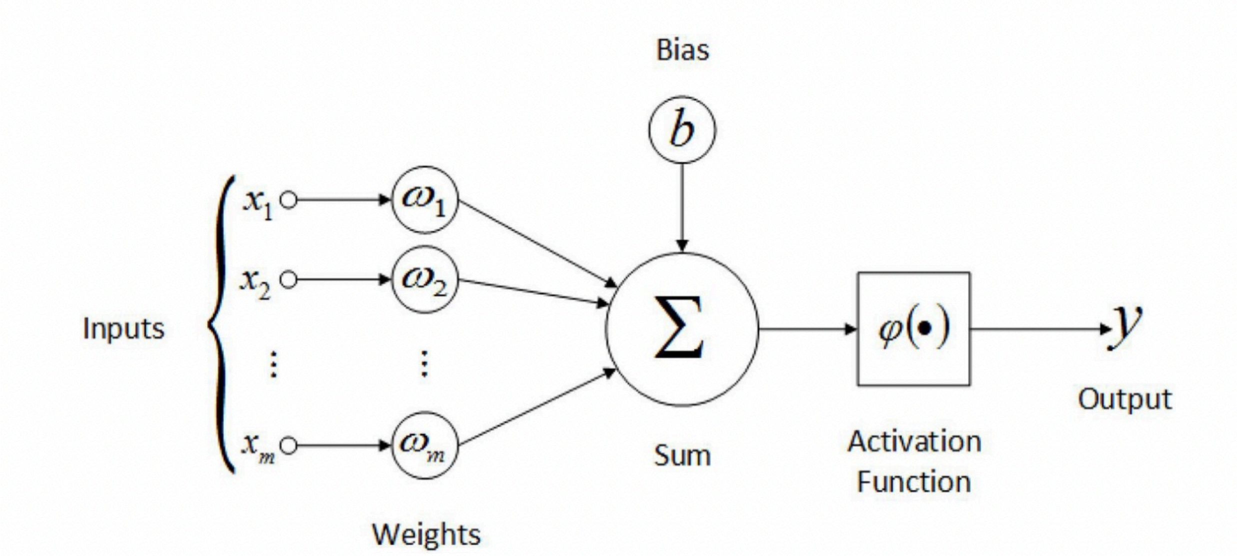
The degraded images are used for training a neural network based on gender. We used Convolutional Neural Networks for classification as it is well known to provide a high classification accuracy.

For this project we have used the Tensor-Flow **Keras** python library for the model creation. The **ReLu** activation layer was used for the hidden layers and the **Sigmoid** activation function was used in the final layer. We used Google Colab for training and testing. All the images were uploaded to the google drive and the drive was mounted to the colab notebook. Model evaluation parameters(**Accuracy, Precision and Recall**) were calculated after the classification was performed. We have not done any fine tuning of the neural network in order to improve the accuracy since the focus of the subject is on Image/Signal Processing.

A Brief Overview about Convolutional Neural Networks

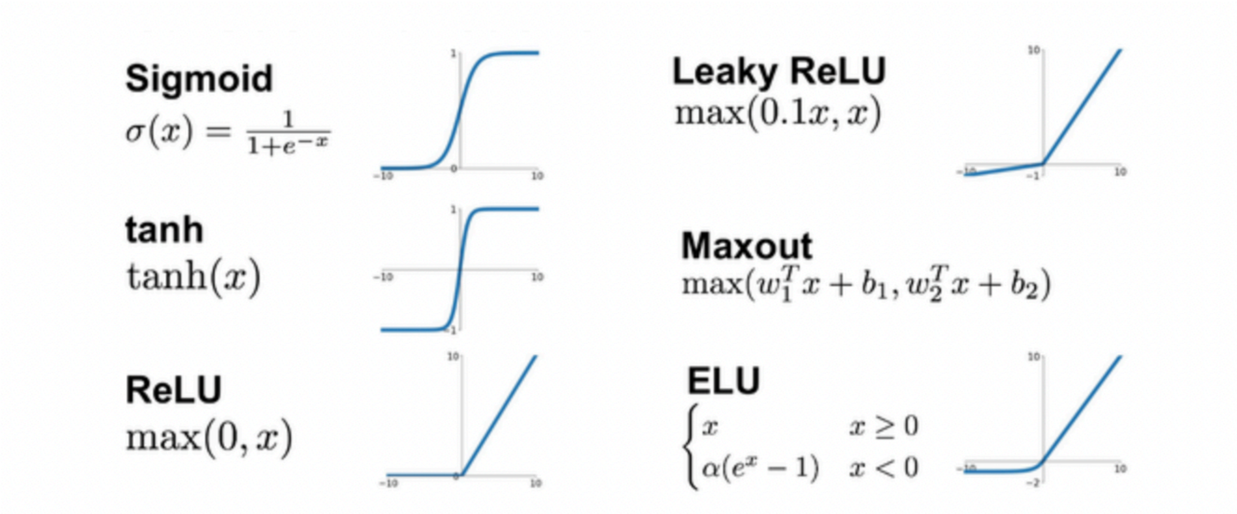
Neural networks are a set of computing systems inspired by the functioning of biological neural network in the human brain.The basic computational unit of a neural network is called a neuron/ perceptron.Networks are made by connecting perceptrons to each other using links like spider web. Each link has an associated weigh and an activation level. Similarly each perceptron has an input function, an activation function and an output.

Here's the pictorial representation of a single neuron with some incoming and outgoing links.

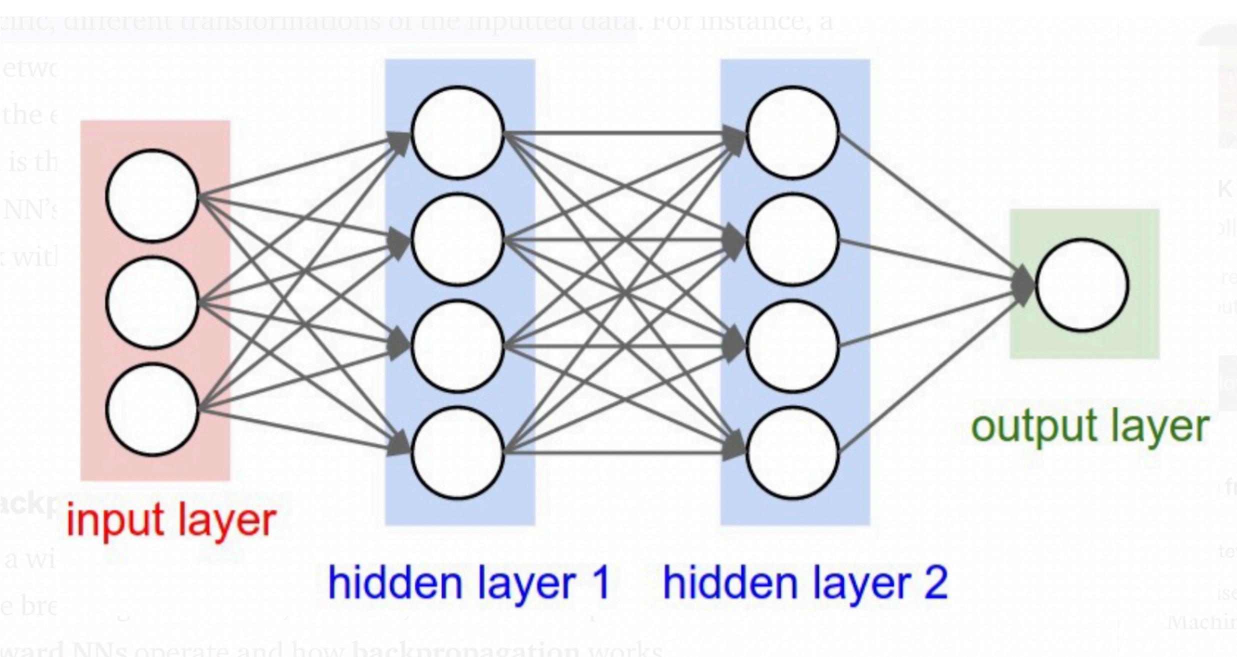


Each input in the networks is multiplied by a weight which determines its respective relevance. The weighted sum is calculated and a bias is added to it. (a bias allows to shift the activation function left or right).The activation function is applied to the sum and used to decide whether the neuron is activated or not.

Here're some commonly used activation functions.



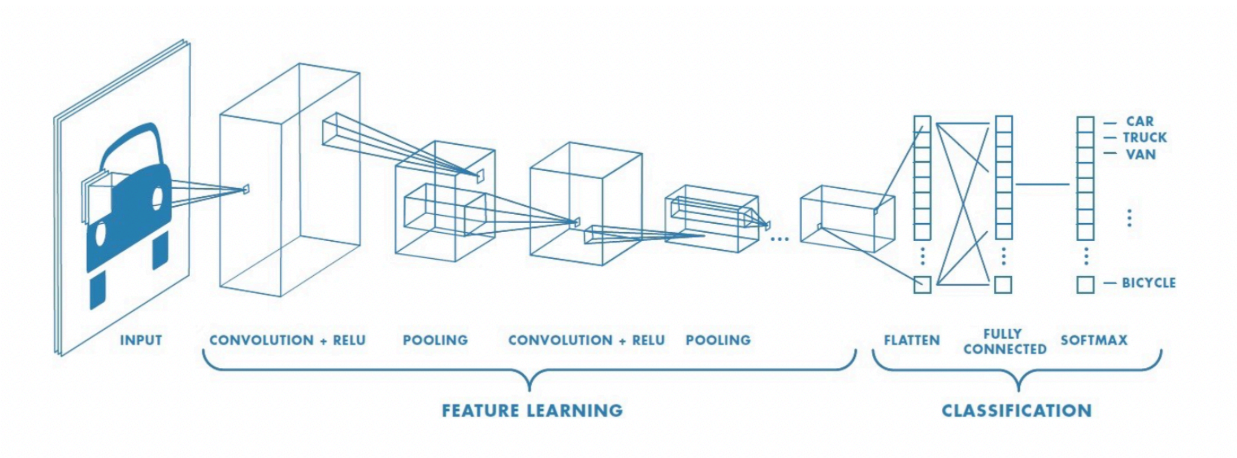
Here's a representation of a Neural Network with many layers.



Firstly, the input layer gets the input data that has to be fed to the neural network. Secondly, the hidden layers perform nonlinear transformations of the inputs entered into the network. There can be many hidden layers within a neural network. Each hidden layer is responsible for a specific transformation of the data. Finally, the output layer shows the final result of all the work carried out by the hidden layers.

Convolutional Neural Networks are a class of deep neural networks mostly used in image recognition, image classification and object detection. Studies show that CNN is more efficient and faster than a regular deep neural network for problems related to computer vision.Each image passes through a series of convolutional layers with filters (kernels), pooling, fully connected layers, and finally through a Softmax/Sigmoid function.

Here's the pictorial representation of a Convolutional Neural Network

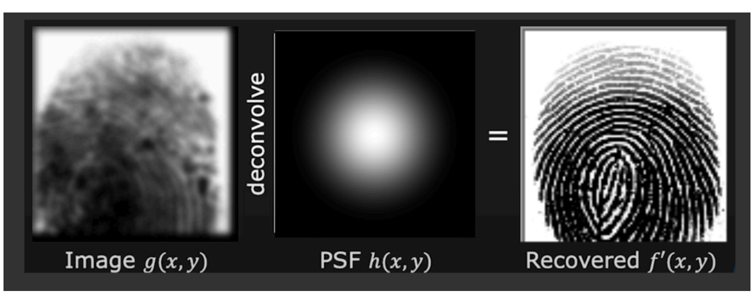


The convolution layer extracts features from the input image such as edges, colors, corners etc.Pooling is done to decrement the computational power by decreasing the dimensions of the feature matrix. As a result, extracting the dominant features. The purpose of the fully connected layer is to classify the input image into various classes based on training data set.

3.Restoration of Images, Training and Classification

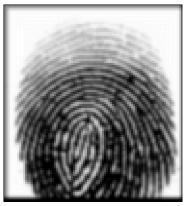
Restoration of degraded images not corrupted by noise

In the case of images that are not corrupted by noise, restoration was fairly straight forward. A program was written that iterated through an array of different sigma values to generate different kernels. The kernel for which the best output was obtained was used to restore all the images in the dataset using deconvolution technique.

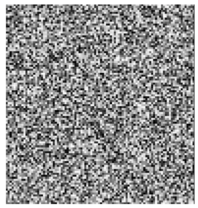


After deconvolution lower frequencies were removed using a high pass filter and then thresholded using adaptive thresholding for better classification accuracy.

Here's the result of trying to recover blurred image with gaussian kernels of different sigma values.



High Sigma Value.



Low Sigma Value

Perfect Deconvolution

Restoration of degraded corrupted by noise

As mentioned above, in real world most of the images are corrupted by noise and applying simple deconvolution technique enhances the noises. So we used Weiner filter to restore the degraded images that are corrupted by noise. Using Weiner filter helps degradation while attenuating the noise.

Here's the expression of Weiner filter

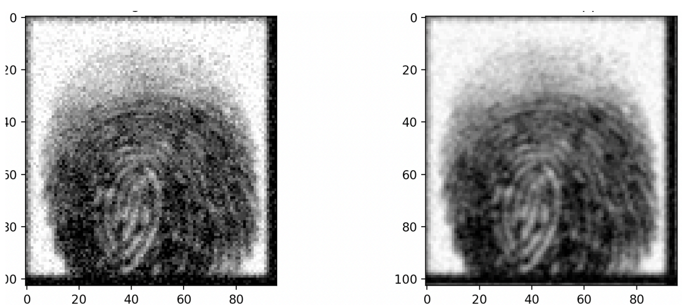
Weiner Filter $\stackrel{\text{def}}{=}$ $\boxed{W(u,v) = \frac{1}{H(u,v)}\left[\frac{1}{1+\frac{NSR(u,v)}{|H(u,v)|^2}}\right]}$

Noise-to-Signal Ratio, $NSR(u,v)$:

$$NSR(u,v) = \frac{\text{Power of Noise at } (u,v)}{\text{Power of Signal (Scene) at } (u,v)} = \frac{|N(u,v)|^2}{|F(u,v)|^2}$$

H(u,v) is the expression of the Kernel used for deconvolution(Gaussian Kernel in this case)

Result of Deconvolution with Weiner filter



Weiner filter did not give satisfactory result as expected. A better restoration can be performed by trying various NSR values.

Once the Image Processing is done, the labelled images are all uploaded to the drive for reclassification and training. Evaluation parameters were then calculated and the results were compared between the previous ones.

Result and Analysis:

As mentioned earlier, the evaluation parameters used for assessing the performance were **Accuracy,Precision and Recall.** The Baseline classification gave a classification accuracy of **79%** with a precision score of **75%**, Recall score of **99.2%.** Image restoration increased the accuracy and precision by **5%** with an accuracy of **83%**, a precision score of **79%**, Recall score of **99.7**. Here's the summary of Performance measures.

	Performance Measures		
Image Processing Technique	**Accuracy**	**Precision**	**Recall**
Degraded Image	0.7933	0.7544	0.9923
Enhanced Image	0.8349	0.7959	0.9974

From the result it can be inferred that we haven't made a quantum jump in the evaluation parameters after Image Processing was performed. However, reasonable improvement was observed after Image restoration and enhancement. One possible reason can be that the dataset might be skewed which affects the training. Also, Convolutional Neural Networks is in itself a very powerful classification algorithm. A fine tuning of the CNN would have given much better accuracy and other measures. Image processing could have further improved it reasonably. But we haven't laid focus on fine tuning the CNN as it was beyond the scope of this course.

Conclusion:

We have observed a reasonable increase in the evaluation parameters after image processing was performed on the dataset. The classification accuracy is observed to be decreasing after a certain epoch due to overfitting. Since Convolutional Neural Networks in itself is a highly sophisticated algorithm for image classification, an exceptional jump in evaluation parameters could not be achieved in this project. Our focus was laid mostly on the image processing side of things rather than fine tuning of the CNN to improve accuracy and other performance measures. However, it is very clear that Image processing techniques that are used above, if used in conjunction with a fine tuned CNN with more layers, can give much better Accuracy, Precision and Recall values.

References:

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