# Minutiae-based Fingerprint Extraction and Recognition

The minutiae-based fingerprint extraction and recognition algorithm is a **set of techniques** used to extract feature points or descriptors known as **“minutiae”**. Minutiae refer to certain small plot points on a fingerprint. These small plot points include characteristics such as **ridge bifurcation, the ridge ending**, ([What is Minutiae? | Webopedia](https://www.webopedia.com/definitions/minutiae/)) as well as the orientation defined as the local ridge orientation of the associated ridge. **A ridge bifurcation is defined as the point where a ridge diverges into branch ridges.**

**Whereas a ridge ending is the point where a ridge ends abruptly**

The number of minutiae points on each fingerprint sample differ from one fingerprint image to another. Depending on the resolution of the fingerprint image, one fingerprint can generate up to 100 minutiae features ([Minutiae-based Fingerprint Extraction and Recognition | IntechOpen](https://www.intechopen.com/chapters/16502))

These extracted minutiae features are then compared to the feature points of other fingerprint template images for fingerprint recognition and matching. The minimum number of matching pairs of minutiae required to declare that two template fingerprints match is at least 12 minutiae features ([Fast\_Fourier\_transform\_for\_fingerprint\_enhancement.pdf](file:///C:\Users\Andy\Downloads\Documents\Fast_Fourier_transform_for_fingerprint_enhancement.pdf))

## Procedures involved in extracting minutiae features

To obtain these minutiae points, a series of frameworks are constructed and used.

### Normalization

Normalization also referred to as histogram stretching or contrast stretching is a process which involves changing the range of pixel intensity values ([Normalization (image processing) - Wikipedia](https://en.wikipedia.org/wiki/Normalization_(image_processing)#:~:text=In%20image%20processing%2C%20normalization%20is,contrast%20stretching%20or%20histogram%20stretching.)). The end result is a high contrast image with much clearer details**. In the case of fingerprint images, it makes finer details such as ridges much more “refined”.** In an ideal fingerprint image, lines of ridges flow in a constant direction. However, due to certain conditions such as, cuts and wetness of the skin, incorrect finger pressure when taking a reading or image noise generated as a result of the sensor, poor quality images are generated which may lead to the generation of multiple false minutiae hence the need for normalization. ([FULLTEXT01\_2.pdf](file:///C:\Users\Andy\Downloads\Documents\FULLTEXT01_2.pdf)), In minutiae extraction, one of the most popular choices of normalization is the Gabor Filter.

**The Gabor filter** is a linear filter used as a normalization technique, it also functions as a tool for feature extraction, edge detection and texture analysis. The Gabor filter amplifies a band of frequencies and rejects the others ([Through The Eyes of Gabor Filter. The Gabor filter, named after Dennis… | by Anuj shah (Exploring Neurons) | Medium](https://medium.com/@anuj_shah/through-the-eyes-of-gabor-filter-17d1fdb3ac97)). By rejecting some of these color frequencies, the variation between gray values along the ridges are also reduced thereby making it easier to have more contrast in the image.

**TLDR: Normalization involves creating a color histogram with color values from 0 to 255 on x-axis and intensity on y-axis, tune the histogram to ensure all intensities are on the same level (histogram equalization), some pixels at specific intensities will never balance out so you remove them with a filter like the Gabor Filter and then refine again.**

### Binarization/Segmentation

The next step after normalization is to binarize that image. Image binarization is the process of taking a normalized grayscale image and converting all its pixels it black and white, essentially reducing the color information from 255 shades of gray to two colors, black and white with values of 0 and 255 respectively. Binarization is done to preserve the characteristics of the ridge structure while removing some of the cohesion between patterns. ([\*Erwin\_2019\_J.\_Phys.\_\_Conf.\_Ser.\_1196\_012045.pdf](file:///C:\Users\Andy\Downloads\Documents\Erwin_2019_J._Phys.__Conf._Ser._1196_012045.pdf))

The process of binarization works by finding a threshold value in the color histogram. The threshold value is a value that divides the histogram into two parts. Each representing one of two layers; the background layer and the object itself in this case, the pattern contained in the fingerprint.

The threshold value cannot be accurately calculated but a good prediction can be made by dividing the image into a block and its mean and variance, calculated for each block. Next, the average the mean and variance of all the blocks are calculated. From this average, the relative mean and variance are also calculated. The threshold value for foreground, in this case the ridges of the fingerprint will be represented as the average of the variance and the background, the average mean. [enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)

For instance, assume a threshold value of **126** has been chosen for the foreground, pixels with values less than 126 would be set to 0 or black while pixels with values greater than 126 would have their values set to 255 or white. ([Image binarization (1) : Introduction – The Craft of Coding (wordpress.com)](https://craftofcoding.wordpress.com/2017/02/13/image-binarization-1-introduction/))

### Fast Fourier Transform

Following the binarization process, some of the ridges may be broken as a result of having their pixel values greater than the threshold value and as such assigned values of 255 or white. The Fast Fourier Transform (FFT) is then used to reconnect these broken ridges. The Fast Fourier Transform is an image enhancement technique used to transform an image between the spatial and frequency domain**. (Spatial domain deals with image as is, that is, the value of pixels changing with respect to the scene BUT frequency domain deals with the rate at which the pixel values are changing in the spatial domain)** [Introduction to Frequency domain (tutorialspoint.com)](https://www.tutorialspoint.com/dip/introduction_to_frequency_domain.htm#:~:text=Difference%20between%20spatial%20domain%20and,are%20changing%20in%20spatial%20domain.)

Any image represented in a frequency domain has two major components.

* High Frequency components which correspond to the edges in the image
* Low Frequency components which correspond to the smooth regions of the image

Fast Fourier transformation decomposes the source image into its spectral information. For instance, its **directional information** which includes respective sines and cosines which reveal a repeating pattern within the image. This orientation data allows the reconnection of broken ridges.

By transforming the source image into the frequency domain, the FFT preserves all original data. [Fast\_Fourier\_transform\_for\_fingerprint\_enhancement.pdf](file:///C:\Users\Andy\Downloads\Documents\Fast_Fourier_transform_for_fingerprint_enhancement.pdf) in addition to further removing noise that may exist in the image

FFT is performed on fingerprint images by extracting a set of pixels from a small region of the source image, the image is subsequently divided into overlapping blocks with powers of 2 (two). **The directional information** of that specific **block** is calculated. **Should a block contain two or more parallel edges, then the dominant frequencies of that block correspond to the ridges in that block. (** [\*1-s2.0-S1877050915001477-main\_2.pdf](file:///C:\Users\Andy\Downloads\Documents\1-s2.0-S1877050915001477-main_2.pdf)**).**

Dominant frequencies refer to a sinusoid which consists of the following:

* Spatial Frequency – Deals with brightness of the image
* Magnitude – Deals with contrast
* Phase – Refers to color information

In order to enhance a specific block by its dominant frequencies, it is possible to multiple the FFT of the block by its magnitude a set number of times making the parallel ridges finely separated and thick. It is also possible to square or cube the magnitude of the FFT as this leads to better results, however, this technique obscures the minutiae. [1-s2.0-S1877050915001477-main\_2.pdf](file:///C:\Users\Andy\Downloads\Documents\1-s2.0-S1877050915001477-main_2.pdf). **Rather than multiplying by whole factors, a fraction of the value of the magnitude is used. (MAYBE REMOVE THIS LINE AND USE AS OBSERVATION)**

### Thinning

Thinning is an image processing technique that involves reducing the thickness of each line of ridge pattern till the width is shrunk enough to become a single or one (1) pixel. This process is done to identify the exact pattern of the fingerprint which in turn makes feature/minutiae extraction possible. [2013\_71.pdf](file:///C:\Users\Andy\Downloads\Documents\2013_71.pdf)

The thinning process is carried out by applying three (3) boxes of matrices where each box contains a 3x3 matrix and one 4x4 matrices.

1. Diagonal Matrices: This box contains a 3x3 matrices which thin diagonal lines. If any two pixels lie adjacent to each other at an angle of and are connected by a third pixel in a angle, the third pixel is eliminated there by preserving the continuity of the image
2. Horizontal Matrices: This matrix removes pixels in an image from the top and bottom, leaving the center pixel.
3. Vertical Matrices: this matrix removes the pixels in an image from the left and right, also leaving the center pixel

The horizontal box/matrix is applied first. It is continuously applied till no change occurs from one iteration to another. The same process is repeated using the vertical box/matrix followed by the diagonal box/matrix. [\*A\_Novel\_Thinning\_Algorithm\_with\_Fingerpr.pdf](file:///C:\Users\Andy\Downloads\Documents\A_Novel_Thinning_Algorithm_with_Fingerpr.pdf)

For an image to be considered properly thinned, each ridge should be thinned to its central pixel. After an image is thinned, further removal of pixels is not possible.

### Minutiae Extraction

In this stage, all minutiae feature points, that is, ridge terminations and bifurcations. Appropriate minutiae feature points are extracted by applying a filter of a matrices over the region of interest (ROI) in the thinned image by following some rules:

1. If the central pixel is ‘1’ and the sum of pixels inside the block is ‘2’, then that central pixel is a ridge termination
2. If the central pixel is ‘1’ and the sum is ‘4’ then the central pixel is a bifurcation
3. If the central pixel is some other value than ‘1’, then the central pixel is a regular pixel with no unique point [enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)

#### Region of interest (ROI)

Region of interest (ROI) is the area of the thinned image of interest. The region of interest is found by applying some morphological operations such as opening area, filling, erosion or closing. Specifying the ROI allows for minutiae suppression outside the region. [enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)

#### Minutiae Orientation

Once the minutiae points have been determined, the orientation for both the ridge termination and bifurcation are calculated.

**Termination Orientation:** This is found by using a table of dimensions for different angles of theta. The positions of pixels connected to the center in a ROI block. By keeping the edge pixels, the first non-zero pixels are taken and its location compared to the table to find the corresponding angle for that termination.

**Bifurcation Orientation:** For each bifurcation, there are three bounding non-zero pixels hence the procedure for termination orientation calculation is applied three times instead of once. [enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)

### Terminating False Minutiae

False minutiae consist of broken ridges, minutiae adjacent to each other and minutiae near the borders. Algorithms such as the Fast Fourier Transform aim to reduce the generation of these points, however, as they are not perfect, some false minutiae will still be generated. [Implementation20and20Evaluation20of20NIST20Biometric20Image20Software20for20Fingerprint20Recognition.pdf](file:///C:\Users\Andy\Downloads\Documents\Implementation20and20Evaluation20of20NIST20Biometric20Image20Software20for20Fingerprint20Recognition.pdf)

False minutiae adversely affect matching and as such they need to be trimmed down or removed. This can be done by:

1. Finding the distance between a termination and a bifurcation. If that distance is smaller than a specified number, this point is discarded
2. If the distance between two bifurcations is less than “D”, that point is discarded
3. If the distance between two terminations is less than “D”, that point is discarded
4. If a bifurcation or termination exists on the edge, that point is discarded

[enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)

### Minutiae Matching

Once the false minutiae have been trimmed. A set of the pixel coordinates and orientation angles are generated from the source image. This data is then compared to the data set of the target fingerprint to determine if the source and the target fingerprint images match. [enfingerprint\_SSD08.pdf](file:///C:\Users\Andy\Downloads\Documents\enfingerprint_SSD08.pdf)