I.J. Image, Graphics and Signal Processing, **2024, 5, 62-74**
Published Online on October 8, 2024 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijigsp.2024.05.05

Quality Assessment of Degraded Palmprints Using Enhancement Filters

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Received: 21 January, 2024; Revised: 24 February, 2024; Accepted: 29 March, 2024; Published: 08 October, 2024

Abstract: Image enhancement in the pre-processing stage of biometric systems is a crucial task in image analysis. Image degradation significantly impacts the biometric system's performance, which occurs during biometric image capturing, and demands an appropriate enhancement technique. Generally, biometric images are mixed with full of noise and deformation due to the image capturing process, pressure with sensor surface, and photometric transformations. Therefore, these systems highly demand pure discriminative features for identification, and the system's performance heavily depends on such quality features. Hence, enhancement techniques are typically applied in captured images before go into the feature extraction stage in any biometrics recognition pipeline. In palmprint biometrics, contact-based palmprints consist of several ridges, creases, skin wrinkles, and palm lines, leading to several spurious minutiae during feature extraction. Therefore, selecting an appropriate enhancement technique to make them smooth becomes a significant task. The feature extraction process necessitates a completely pre-processed image to locate key features, which significantly influences the identification performance. Thus, the palmprint system's performance can be enhanced by exploiting competent enhancement filters. Palmprints have reported a lack of novelty in enhancement techniques rather than more centering on feature encoding and matching techniques. Some enhancement techniques in fingerprints were adopted for palmprints in the past. However, there is no clear evidence of their impact on image quality, and to what extent they affect the quality in specific applications. Further, frequency level filters such as the Gabor and Fourier transforms exploited in fingerprints would not be practically feasible for palmprints due to the computational cost for a larger surface area. Thus, it opens an investigation for utilising enhancement techniques in degraded palmprints in a different direction. This work delves into a preliminary investigation of the usage of existing enhancement techniques utilised for pre-processing of contact fingerprint images and biomedical images. Several enhancement filters were experimented on severely degraded palmprints, and the image quality was measured using image quality metrics. The High-boost filter comparatively performed better peak-signal-to-noise ratio, while other filters affected the image quality. The experiment is further extended to compare the identification performance of degraded palmprints in the presence and absence of enhanced images. The results reveal that the enhanced images with the filter that has the highest peak signal-to-noise ratio (High boost filter) only show an increased genuine accept rate compared to the ground truth value. The High-boost filter slightly decreases the system's equal error rate, indicating the potential of exploiting a pre-enhancement technique on degraded prints with an appropriate filter without compromising the raw image quality. Optimised enhancement techniques could be another initiative for addressing the severity of image degradation in contact handprints. Doing so they could be successfully exploited in civilian applications like access control along with other applications. Further, utilising appropriate enhancement filters for degraded palmprints can enhance the existing palmprint system's performance in forensics, and make it more reliable for legal outcomes.

Index Terms: High-boost filter, palmprint, spatial filters, quality analysis, PSNR, MSE.

1. Introduction

Image enhancement is one of the key aspects of any image processing application. It demands specific pre-processing steps during image acquisition to address issues like image deformation and degradation. The clarity of an image is affected by sensor constraints, the position of the object, and different illumination and lighting conditions. Consequently, researchers encounter challenges during the enhancement process, and the images are acquired in diverse scenarios and applications. For instance, in biometrics, biomedical, and computer vision-related research domains, a large number of images are processed at a time. This requires enhancement techniques to rectify the defective images, as they are full of deformations caused by noise, sensor pressure, and photometric transformations such as illumination, contrast, and blurring.

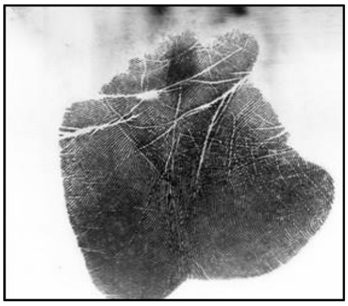


Fig. 1. A typical contact-based palmprint from the THUPALMLAB database.

In biometric applications, image deformation is more severe in touch-based sensors, where biometric traits are applied with pressure on the sensor surface. Therefore, the feature extraction process in such systems highly requires distinct discriminative features for image comparison and matching. The biometric systems will not work well and performance will suffer if the features are treated with noise. Feature extraction necessitates a pre-processed image with enhancements to locate features in degraded images. The pre-processing phase significantly influences the classification accuracy of matching images, making it crucial to select a promising enhancement technique based on the biometric modality and acquisition mode. Therefore, selecting a useful and promising enhancement technique based on the biometric modality and acquisition mode becomes more projecting in this research.

The focus of image enhancement is to highlight useful information by visualizing more hidden details in an image. Passing degraded or low-quality images through enhancement filters results in high-quality images that can be applied for specific applications. For image enhancement, there are various filters available in spatial and frequency domains, and they have been used to improve images for different applications and purposes. However, the filters that work well in one application may not yield the same results in another application. This implies that the best and most effective enhancement technique exploited in biomedical applications may not work well for biometric applications. Therefore, selecting the appropriate enhancement filter for a specific application and purpose is a critical task.

In biometric applications, different enhancement techniques were employed for various biometric traits such as fingerprint, palmprint, iris, face, and ear. Each of these techniques requires special consideration depending on whether the image acquisition mode is contact-based or contactless. This is because the challenges faced in contact-based image acquisition differ from those in contactless acquisition, leading to significant variations in geometric and photometric constraints. The majority of biometric traits captured using contact-based sensors are fingerprints and palmprints, which have been primarily utilized in civilian and forensic applications. However, palmprints have not received as much attention compared to fingerprints in civilian applications. If there is a precise biometric system in civilian applications, a full-hand biometric system can be in practice while incorporating fingerprints with palmprints, as the increased surface area of a biometric can yield more feature points and enhance performance. This can be achieved by processing quality images that can be processed through promising enhancement techniques. On the other hand, high-resolution palmprints require a precise identification system due to their forensic significance. The present nature of palmprints found at crime scenes is often of poor quality, which highlights the critical need for enhancement in an identification system. Errors during enhancement can result in the extraction of less distinctive features, ultimately compromising the biometric system’s identification performance [1].

Recent palmprint studies have predominantly focused on biometric matching algorithms, with a lack of attention given to enhancement-related works and their performance. The performance of a palmprint system can be enhanced by using quality images, which can be achieved through the use of competent enhancement filters. Previous research in palmprints has utilised enhancement techniques borrowed from fingerprint enhancement. In most cases, it was assumed that the ridge structure of palmprints is as smooth as fingerprints. Conversely, contact-based palmprints consist of several ridges, creases, skin wrinkles and palm lines that are interconnected, as illustrated in Figure 1. The large surface area and sudden changes in ridge patterns require a more robust enhancement approach. The current research on image enhancement reveals a lack of focus on contact-based palmprint images, as opposed to contactless palmprints [2, 3, 4]. The enhancement methods used for contactless scenarios are not directly applicable to the other scenarios, as they primarily address photometric issues in contactless images. This highlights a deficiency in contact-based palmprints, which are extensively used in forensic investigations and could also be applied much as full-hand biometrics in civilian settings if there is a notable performance improvement.

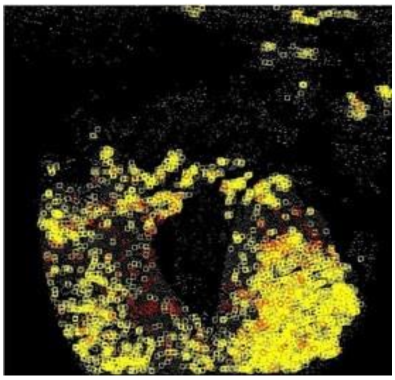


Fig. 2. Minutiae localisation in a palmprint shows a bombardment of true and false minutiae due to image degradation.

Therefore, this work is designed to develop an appropriate enhancement technique that is suitable for degraded contact-based palmprint images. The degraded palmprints result in more deviation in original quality, and yield several spurious minutiae (ridge branches and endings) as shown in Figure 2. If the primary features used in the palmprint system are ridge or minutiae, the enhancement process of such images becomes a crucial task. A few sets of enhancement filters have been investigated with contact-based palmprints in the past. However, there is no evidence of to what extent these filters can help to improve the biometric system performance without affecting the quality of images.

Present enhancement filters are available in spatial and frequency domains, and they have been used to enhance the images for various purposes and scenarios. For degraded palmprints, it necessitates a further investigation of whether a spatial or frequency domain-based preliminary enhancement is necessary early in the stage. If yes, selecting an appropriate filter or determining the use of any filter is an important step when handling the degradation of the images. Researchers need to know to what extent the selected filters work well and produce better-quality images during enhancement. Even a slight enhancement of an image can improve the system's performance significantly. In contrast, the modification can deform the images to a certain extent as well. Utilising such enhanced images within the system would not yield a significant performance change during biometric recognition. This reveals that not all enhancement techniques are very much useful for a certain application instead of wasting computational cost. Thus, there is a need for an investigation of the present image enhancement filters, and an evaluation to determine to what extent they can be utilised to preserve the quality of the original image. This work focuses on a preliminary investigation for exploiting an appropriate enhancement technique for pre-processing in contact-degraded palmprints by exploring existing filters in palmprints, and other filters that performed well in both biomedical and biometric applications.

The contribution of this work highlights i) the investigation of enhancement techniques present for the biomedical imaging domain; ii) the investigation of the appropriateness of enhancement techniques present with biometrics, particularly for fingerprints and palmprints; iii) the investigation of quality preservation after each technique is applied with the raw image and iv) the investigation of identification performance in the presence and absence of enhancement techniques.

2. Literature Review

Enhancement techniques in image processing focus on enhancing the visual characteristics of an image, which depends upon various factors such as image content and specific application. Enhancement techniques in image processing are categorised into two domains: i) Spatial filters and ii) Frequency filters [5]. The objectives of the process are to adjust the image's photometric characteristics such as brightness, contrast, and grey-level intensity, and sharpen the image dis- criminatory features such as key points, lines and edges. Biometric, biomedical, and many object detection applications in computer vision research use image enhancement in spatial and frequency domains. The majority of biometric applications utilized image analysis for biometric identification and verification in civilian and forensic applications [1, 6, 7]. In contrast, the majority of biomedical applications analyse images with enhancement techniques to precisely detect diseases by differentiating defective images from a healthy person's images. For instance, the work in [8] used vascular structure enhancement for cardiovascular disease screening. Similarly, biometric applications also adopted some enhancement techniques for the identification of one individual from another.

Biometric traits for the identification process are captured in contact and contactless-based image acquisition modes. Images from the two different biometric captures require different types of enhancement filters which depend on the deformation and degradation the images hold. In a contact-based biometric system, fingerprints and palmprints have been widely used. Even though palmprints have received a lack of attention as compared with fingerprints, high-resolution palmprints demand a precise identification system due to their forensic value and the presence of poor-quality images in crime scenes, which make them a prioritized biometric option in large-scale biometric systems. Extraction of less discriminatory features in poor-quality images leads to deteriorating of the palmprint system's identification performance. This necessitates a precise enhancement process, which depends on the quality of input images or the nature of the application.

2.1 Enhancement in Fingerprints and Palmprints

A palmprint recognition system whether in civilian or forensic applications, should undergo the process of enhancement, feature extraction, and matching to result in a precise recognition result. The enhancement in palmprints has been investigated to a certain extent in the past [9]. However, the researchers need to determine whether a technique applied to a particular type of image actually makes sense by revealing a quality effect when the images are in a range of degraded conditions. Because contact images can be severely degraded when pressing a finger or palm on the sensor surface with various pressure ranges. It is difficult to restore the actual nature of the image without affecting its quality.

Feature representation in palmprints is primarily addressed by ridges or minutiae information where endpoints and branches of the ridges are localised as minutiae [10]. Two images are compared or matched for similarity using the identified minutiae-based features such as minutiae orientation, minutiae types (endpoint and bifurcation), ridge density, ridge orientation, etc. When there is much degradation or skin stretch on the two images matched, then the features identified would not be robust due to the distortions, which deteriorate the performance of the identification system while consuming time for processing unnecessary features and noise reduction.

Recent studies in palmprints have reported a lack of novelty in enhancement techniques rather than more centering on feature representation and matching techniques. Further, enhancement in contactless palmprints dominates in present days [2, 3, 4], while contact-based prints are left behind. In contactless images, researchers have widely employed image enhancement techniques for palmprint recognition and verification by reducing matching errors [2, 11]. Despite the emergence of image enhancement techniques that drew a way for shaping the palmprint recognition task [12], researchers have not yet agreed on a single reliable and effective image enhancement technique in both contact and contactless palmprint systems [2, 11]. Improving contactless image quality becomes crucial, as recognition performance depends on the identified visual information [13]. The work in [14] used PalmNet based on a convolutional neural network (CNN) to tune palmprint-specific filters based on Gabor responses and principal component analysis (PCA). Emerging methods have attracted much interest in contactless palmprint by exploiting a combination of filters to enhance the image quality [15]. Because, contrast in contactless images is important for extracting features with clarity in a certain environment [11], as high-contrast images clearly differentiate bright and dark regions [16]. The work in [17] exploited palmprint images with a combination of 3W filters such as wavelet filter, Wiener filter, and weighted filter for managing texture details and reducing noise, respectively. However, the techniques exploited in contactless images cannot be directly applied to contact-based palmprints, as they are more centric for resolving photometric effects.

The majority of contact-based palmprint enhancement techniques have been adopted from fingerprint enhancement based on the assumption that ridge patterns in fingerprints and palmprints are the same. Several enhancement strategies have been used in fingerprint images [18, 19, 20]. The general and primitive processes in fingerprint enhancement are normalization, local orientation estimation, local frequency estimation, region mask estimation, and filtering [18]. There is a major difference between fingerprint and palmprint images' ridge patterns where palmprints consist of several ridges, wrinkles, and palm lines in a complex structure within a large surface area. Therefore, the same algorithm exploited in fingerprint images cannot be directly applied to contact-based palmprints.

Contextual filtering techniques by enhancing the quality of ridge/valley patterns and fixing broken ridges and scars were employed mostly in palmprints [18]. Contextual filtering is performed by Gabor filters where ridge orientation and frequency are locally estimated. Precisely estimating local ridge angles is necessary as this will be utilised in a later stage of feature extraction, and therefore, reliable enhancement is necessary. For frequency estimation, Jain and Feng [21] exploited a DFT analysis in palmprints, while Hong et al. [18] estimated ridge frequencies in fingerprints based on the x-signature method. To compute frequency, the fingerprint is divided into blocks, and computing the ratio of the number of ridges and the distance between the first and the last ridge in each block. This method was efficient, straightforward, and gave good results in fingerprints. Cappelli et al. [4] proposed contextual filtering using Gabor filters for palmprint enhancement, which was already introduced by Hong et al. [18] for fingerprints. The researchers [4] extended the x-signature method for palmprints, tuning the filter parameters based on image features. However, the main issue experienced in palmprint enhancement is in terms of local ridge orientation and frequency estimation. For palmprint ridge pattern enhancement, the filters were designed to enhance ridge flow patterns using local ridge frequency and orientation information [22].

Contextual methods fail in palmprint recognition because palmprints typically consist of a larger number of complex creases, and their ridge structure is not similar to fingerprints. To mitigate this issue, Cappelli et al. [4] initially exploited an adaptive orientation estimation algorithm [21] on fingerprints with low quality, and extended to palmprints by striking a balance between accuracy and efficiency. Jain and Feng [21] proposed an iterative edge-linking algorithm using the DFT to address the severity of distorted palmprints. Chen et al. [23] introduced a palmprint orientation estimation algorithm that involves extracting creases and determining orientations using the DFT [21] in areas with fewer creases. However, palmprint surface area is larger than fingerprints, which can result in a computational cost during complete hand processing.

In contact palmprints, gradient-based and region-growing techniques have been used [1]. Filters were applied in spatial and frequency domains [24] where they were applied patch-wise using the Fourier transform or Gabor filter [25]. These approaches are well supported with fingerprints but cannot adapt to varying ridge orientation and frequency in palmprint ridge patterns [25], resulting in an error-prone enhancement process. Jain et al. exploited Discrete Fourier

Transform based enhancement by assuming palmprints have rigid ridge patterns [21], while Dai et al. [26] applied the same approach on larger patches 64×64 to minimise computational complexity. Computation cost, varying ridge orientation, and frequency need to be overcome in their work. The work in [27] performed Curvelet-based palmprint enhancement with noise. However, this did not support improving the contrast of an image. The work in [28] used unsharp masking for the contrast enhancement of a palmprint image, and the replacement of a high-pass filter using steerable filters in unsharp masking was exploited in this work. This method improves the image quality of palmprint wrinkles, which then results in a better recognition performance. On the other hand, the work in [9] investigated some enhancement filters in palm vein applications as well.

For fingerprint biometrics, similar types of filters have already been in practice. It is important to use some set of enhancement techniques that can significantly enhance the palmprint images and make a positive impact on the identification accuracy of the palmprint system. It is noted that the work in [29] investigated the use of enhancement techniques in contactless hyperspectral palmprint images. However, such techniques cannot directly be applied to contact-based prints, and the contact-based degraded palmprint images are still open for investigation with the appropriateness of the present filters. The filters used for the experiment in degraded palmprint images and their characteristics are illustrated in Table 1.

Table 1. List of filters and their description used for degraded palmprint image enhancement.

Enhancement Techniques	Descriptions
Histogram Equalisation	Enhancement by stretching the histogram into the grayscale range of 0–255.
Un-sharp masking	Enhancement using high-frequency contents.
High boost filter	It is a modified version of High-pass filter. When we need to enhance edges and keep the background, a High boost filter is used.
Laplacian filter	High-pass sharpening filter enhances the edges and line structures.
CLAHE	Contrast Adaptive Histogram Equalisation
Gray-Level slicing	It enhances specific intensity values. It is equal to band-pass filtering. Best suited for X-rays.
Jerman Enhancement Filter	They are used to enhance vessel and sphere-like structures using Hessian eigenvalues.
Unsharp Mask	Sharpening filter to enhance edges and frequency components and smooth the contrast. It yields a high-pass image by subtracting blurred components of an image.

2.2 Enhancement Filters

Different enhancement techniques have been exploited in biometric systems to enhance the images to be well-suited for extracting features and matching. The enhancement techniques for biometric images can be applied in frequency and spatial domains. Frequency or transform domain techniques comprise magnitude (frequency) and phase components. This approach performs enhancement by taking the transformation of the input images where high-frequency components of the images such as curves, edges, and ridges are enhanced by the transform coefficient. Fourier Transform and Discrete Cosine Transform are a few examples of frequency domain enhancement techniques. On the other hand, spatial domain techniques focus on the direct handling of pixels in an image (point processing) where a single pixel is modified at a time, which is the simplest technique of all image enhancement techniques. Examples of point processing techniques are: negative of an image, thresholding, contrast stretching, histogram equalisation, gray level slicing, CLAHE, etc. Further, spatial enhancement such as high boost filtering and unsharp masking are also in practice with image processing applications. However, researchers do not know how much they can positively contribute to the quality preservation of degraded image content. This work investigates a comparative analysis of different spatial-level enhancement techniques available in both biometric and biomedical applications and experiments with degraded or poor-quality contact-based palmprint images. The following section describes a few of the existing enhancement techniques exploited in image processing applications.

2.2.1 CLAHE

It is a modified version and similar to the Histogram Equalization [30] and it is utilised to minimise the noise-related issue and to get visible hidden features of the images.

2.2.2 High Boost Filter

It is a modified version of the High-pass filter. When we need to enhance edges and keep the background, a high boost filter is used.

$$f_{highboost}(a,b) = K * f(a,b) - f_{lowpass}(a,b) \tag{1}$$

Where
$f(a,b)$ is an input image
K is a constant
$f_{lowpass}(a,b)$ is low pass filtered version of $f(a,b)$.

2.2.3 Unsharp masking

It is a smoothing filter. Generally, the image has high-pass and low-pass components. During unsharp masking low-pass components are subtracted from the image [31]. It is expressed in Equation 2 as follows:

$$f_{unsharp}(a,b) = f(a,b) + K * f_{highpass}(a,b) \tag{2}$$

2.2.4 Laplacian filter

It is an edge detector similar to other edge detection operators such as Sobel and Prewitt, which calculates 2^{nd} derivative of the image [32].

Apart from the biometric-related enhancement techniques, the literature reported that the high-boost and high-frequency filters were already in practice for simultaneous denoising and sharpening images in biomedical applications [33]. However, these techniques have been limited in the biomedical domain, and have not yet been practiced with biometrics images. In palmprint applications, the existing enhancement techniques used in the past yield a gap in investigating if the spatial and frequency level filters or the combination of both can be exploited in pre-processing. In other words, we need to check if it is necessary to carry out a preliminary screening for enhancement before passing the image into the transform domain. Therefore, this paper investigates the existing palmprint enhancement techniques with a combination of high-boost and high-frequency filters and measures the quality of images after enhancement. Since there are certain enhancement techniques in practice in biomedical imaging, this work investigates the appropriateness of them in biometric applications as well, particularly in degraded palmprints.

3. Overall Methodology

3.1 Dataset

To investigate the effect of certain enhancement filters on degraded palmprints, the experiment was carried out using a set of degraded palmprints from the THUPALMLAB, a publicly available contact-based palmprint database [34], The database consists of palmprint images acquired from 80 users, captured using a commercial scanner. The images are 2040x2040 pixels at 500 dpi, captured using a commercial scanner with different variations in quality. This dataset has been used to evaluate several contact-based palmprint experiments and applications in the past [35, 36]. We have chosen the hypothenar region of the palm as the work in [35] demonstrated that this area showed better performance compared to other regions.

The dataset used here is with severe low-quality prints as they show a large number of spurious minutiae. The selection of the degraded palmprints is experimentally carried out. To filter the images into low-quality categories, the number of minutiae in each print holds is calculated. The image is deemed highly degraded if the minutiae count is significantly higher, deviating greatly from the average number of minutiae ranges in each print. A manual process is also used to confirm this computation of degraded print selection. A set of degraded palmprint images acquired from 40 users, were treated with the pre-enhancement filters discussed in the literature. The images used for the experiments show a bombardment of minutiae as shown in Figure 3(b). The minutiae set consists of true and fake minutiae due to the degradation (breaking) of ridges which resulted from the contact nature of the prints with the sensor.

3.2 Experimental Setup for Image Quality Assessment

The objective of an enhancement process is to i) enhance contrast, ii) obtain the quality of the image and iii) obtain details with existing frequency without noise. Therefore, the quality of an enhanced image should be measured and the quality metrics should be analysed. There are certain sets of metrics used for quality estimation of the images that are pre-processed using enhancement filters. They are the Peak-Signal-to-Noise Ratio (PSNR), structural similarity index, Mean Squared Error, Normalised Cross Correlation, and Normalised Absolute Error. Table 2 illustrates short descriptions of the quality metrics.

Table 2. Image quality parameters used for the quality estimation [29].

Measure of Image Quality	Descriptions
Mean Square Error	Provides higher quality in image
Peak Signal-to-Noise Ratio	The higher of this value represents higher quality of an image
Structural Similarity Index	It is used to estimate the structural similarity index for measuring image quality.
Normalised cross-correlation	Represents the degree of similarity when two images are compared. It ranges between -1 to 1 and the score value range of one yields higher quality.
Average Difference	A higher average difference value provides lower quality.
Structural Content	Lower structural content shows higher quality.
Maximum Difference	Higher value shows higher quality in the image.
Normalised Absolute Error (NAE)	A metric used for measuring the amount of error in an image. The larger value shows poor quality in the image.

3.3 Experimental Setup for Palmprint Identification

There are three phases of experimental procedures take place:

1. *Pre-enhancement:*

Initially, the images undergo pre-enhancement techniques. The experiment utilizes enhancement filters listed in Table 2, and the enhancement filter with a better performance in quality is chosen for the final enhancement process.

2. *Feature extraction and minutiae localisation:*

Ridge endings and branches are localised as minutiae endpoints and bifurcations, respectively. Figure 3 shows the feature extraction process where localised minutiae set consists of genuine and spurious minutiae.

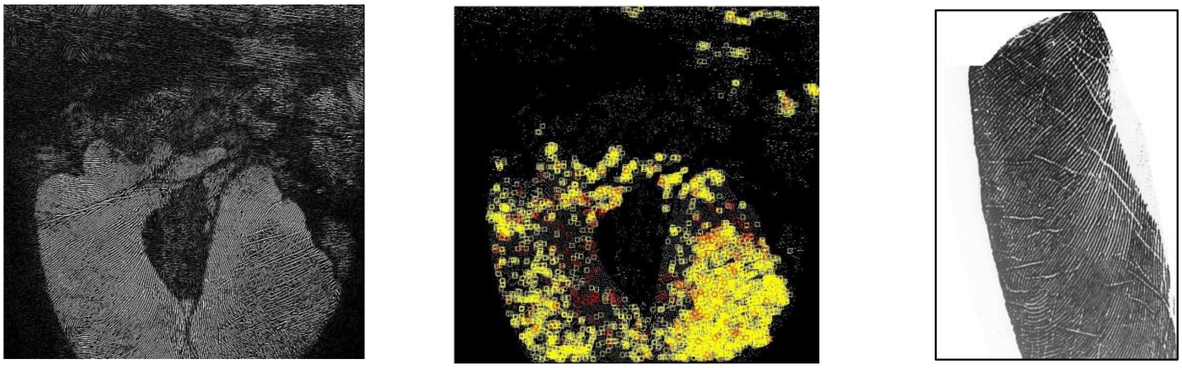
3. *Triangle and Graph Matching:*

For the evaluation of the identification performance of the contact palmprint system, minutiae features are extracted from the pre-processed images. For the matching of these minutiae between two images, an algorithm is derived from a fingerprint system based on minutiae triangles with an extended graph [37]. The algorithm is invariant to geometrical variations of images [38], and is described as follows:

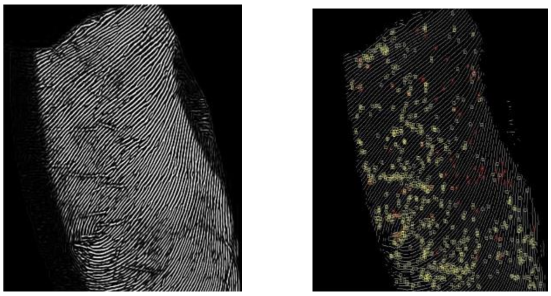
A) Initially, Delaunay triangles are generated from the localised minutiae points. Then, the Delaunay triangles are compared between two images. For the triangle match, the triangle angles and minutiae orientation in each triangle are used. The initially matched triangles are then localised as reference triangles (Figure 4) from which neighbour triangles match starts in the next phase.

B) Based on the reference matched triangles as depicted in Figure 4, adjacent triangles are also compared. If the adjacent triangles are matched, they form sub-graphs and continue to expand. Multiple sub-graphs would emerge from each reference triangle.

C) Finally, from the various sub-graphs, the optimal sub-graphs are chosen based on the number of minutiae they hold. A threshold value for the number of minutiae is assigned for this selection. The remaining sub-graphs are deemed as false graphs as they lack minutiae and are unable to expand due to the limited number of adjacent minutiae matches.



(a) Enhanced Image (b) Bombardment of minutiae localization (c) Hypothenar segment of a full palmprint



(d) Enhancement (e) Localization of minutiae

Fig. 3. The phase of Feature extraction in a palmprint: Bombardment of minutiae is identified with true and false minutiae.

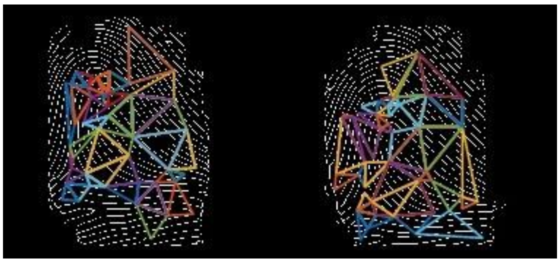


Fig. 4. Matching of two image segments based on the Delaunay triangles.

4. *Score Computation*

Palmprint images acquired from 40 participants are used for image matching, resulting in 2233 genuine matches and 99525 impostor matches. Genuine test is performed by comparing prints between the same person, while impostor test is performed by comparing the prints between different individuals.

The score is computed based on the ratio between the number of matched triangles (*R1*) and the total number of Delaunay triangles (*R2*). Equation 3 represents the ratio where *i* is the number of minutiae in the triangles matched while j is the total number of minutiae in Delaunay triangles.

$$R1 = \frac{i!}{3!(i-3)!} \tag{3}$$

$$R2 = \frac{j!}{3!(j-3)!} \tag{4}$$

$$Ratio = \frac{R1}{R2} \tag{5}$$

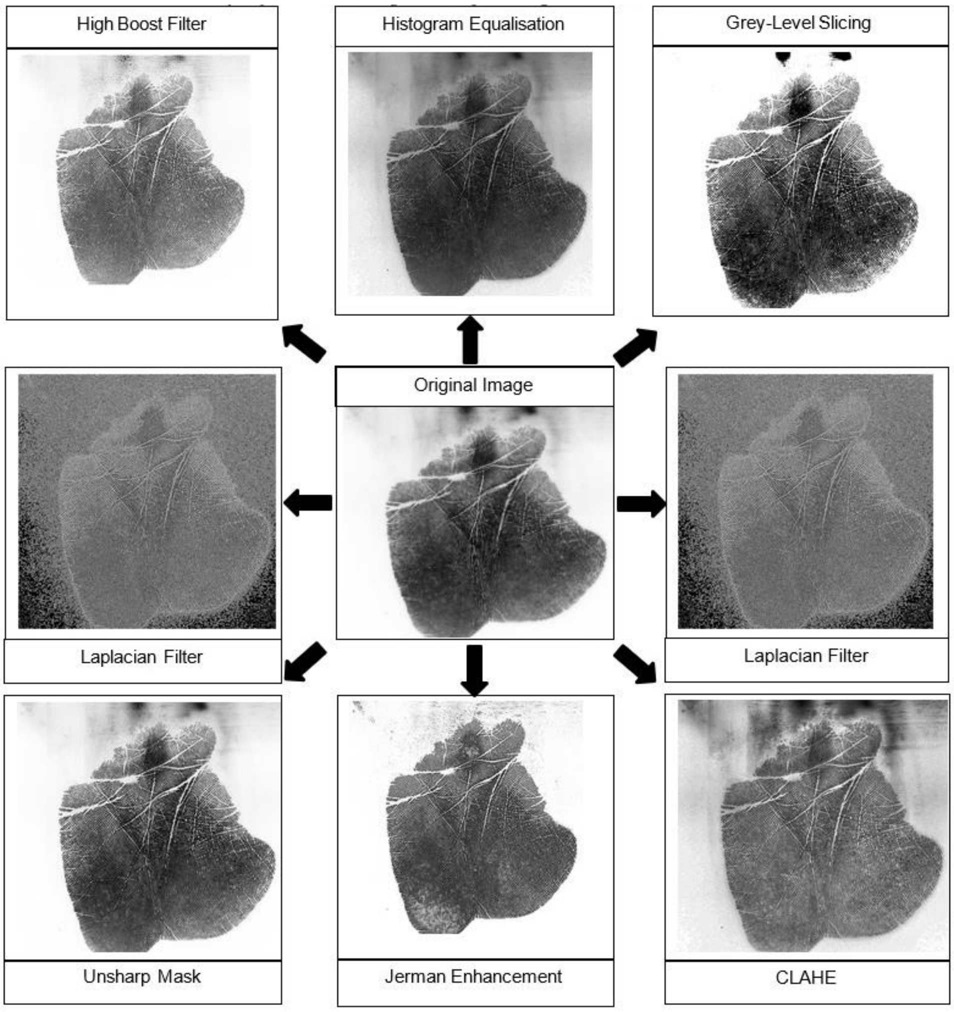


Fig. 5. Palmprint image enhancement using enhancement filters.

4. Results

4.1 Performance of Image Quality Estimation

The experimental output after applying seven enhancement filters to a contact-based palmprint is illustrated in Figure 5, The experiments conducted on degraded palmprints involved evaluating the metrics of PSNR, SSIM, and MSE, which are tabulated in Table 3. Upon analysing the results, the high-boost filter comparatively performed better, achieving the highest PSNR as shown in Figure 6. Specifically, the High-boost filter, Unsharp masking, and Jerman enhancement filters resulted in PSNR values of 36.44, 34.06, and 30.04, respectively.

For the SSI analysis, the unsharp mask performs comparatively a higher value of 0.965, and the high boost and histogram equalisation filters are in the subsequent ranks as shown in Figure 7. When evaluating the MSE, the high boost filter has the lowest value of 14.74. The subsequent values are obtained by the Unsharp mask and Jerman enhancement filters.

The higher ranks in PSNR and SSI, along with lower MSE, indicate better image quality. High boost filter, Unsharp masking, and Jerman enhancement filters are given priority for enhancement while preserving the image quality. An overall analysis of these metrics with various filters is illustrated in Figure 8, where the high boost filter, unsharp masking, and Jerman enhancement filters demonstrate higher PSNR. These filters have been selected for pre-processing and investigating their impact on the performance of the palmprint system.

Table 3. Quality estimation of the image using a list of enhancement filters on a degraded palmprint.

Enhancement Filters	PSNR	SSI	MSE
High Boost Filter	36.44	0.723	14.74
Histogram Equalisation	25.55	0.780	180
Grey-Level Slicing	29.76	0.698	68
Laplacian Filter	26.99	0.195	129.88
CLAHE	26.58	0.683	142.75
Jerman Enhancement Filter	30.04	0.689	64.39
Unsharp Mask	34.06	0.965	25.47
High Boost Filter before Histogram Equalisation	26.51	0.378	145.05
High Boost Filter after Histogram Equalisation	28.59	0.440	89

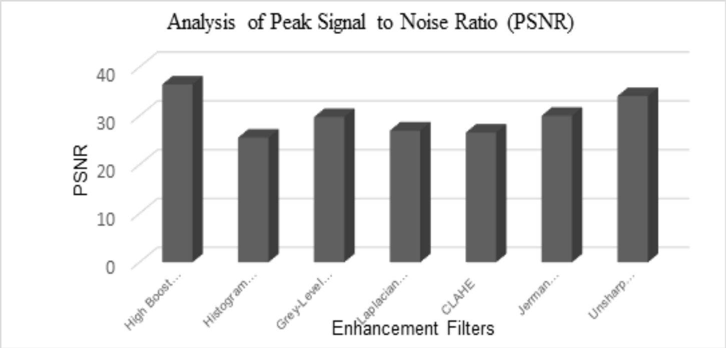


Fig. 6. Analysis of Peak Signal to Noise Ratio (PSNR) with enhancement filters.

4.2 Performance of Palmprint Identification After Enhancement

Initially, the palmprint images are enhanced using chosen filters resulting from the previous experiments. For feature extraction, minutiae points are then identified, representing ridge endings and ridge branches as endpoints and bifurcations, respectively. For minutiae matching between two images, a minutiae-matching algorithm based on minutiae triangles as explained in Section 3.3 is utilised. The algorithm relies on Delaunay triangles and graphs.

For the performance evaluation of the palmprint identification system, genuine and impostor matching scores are computed using the THUPALMLAB palmprint database. The performance metrics include genuine accept rate (GAR), false accept rate (FAR), and equal error rate (EER). Table 4 illustrates the outcomes of GAR, FAR, and EER before applying pre-enhancement techniques, and after enhancement with the High boost filter, Unsharp masking, and Jerman enhancement filters.

It is reported that the use of a high boost enhancement filter resulted in an EER of 7.24%, while an EER of 7.35% is reported when the palmprint is not exposed to pre-enhancement. Despite being a slight improvement, employing the high boost filter for the degraded contact-based palmprint system has a positive impact in terms of EER. This indicates that the filter used for biomedical applications can also be integrated into biometric applications, especially contact-based palmprints.

Enhancement using the Jerman and unsharp masking filters increases the EER from the ground truth value of 7.35% to 7.36% and 8.15%, respectively. Figures 9, 10, and 11 represent the EER of the palmprint system after applying the high boost filter, unsharp masking, and Jerman enhancement filters, respectively. It reveals that not all filters are suitable for enhancement due to the potential alteration in image quality or loss of quality preservation.

Table 4. Performance metrics of palmprint system using pre-enhancement and before applying enhancement.

Enhancement	GAR	FAR	EER
Without Pre-Enhancement	88.34%	1.5%	7.35%
Using High Boost Filter	88.65%	1.5%	7.24%
Un-sharp Masking	87.84%	1.5%	8.15%
Jerman Enhancement Filter	86.96%	1.5%	7.36%

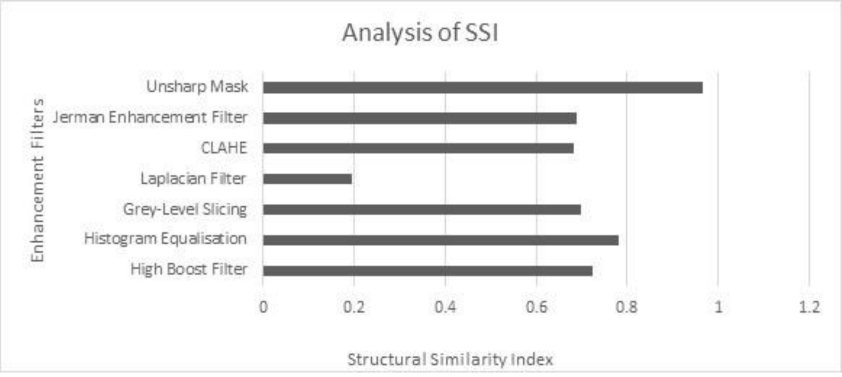


Fig. 7. Analysis of Structural Similarity Index (SSI) with enhancement filters.

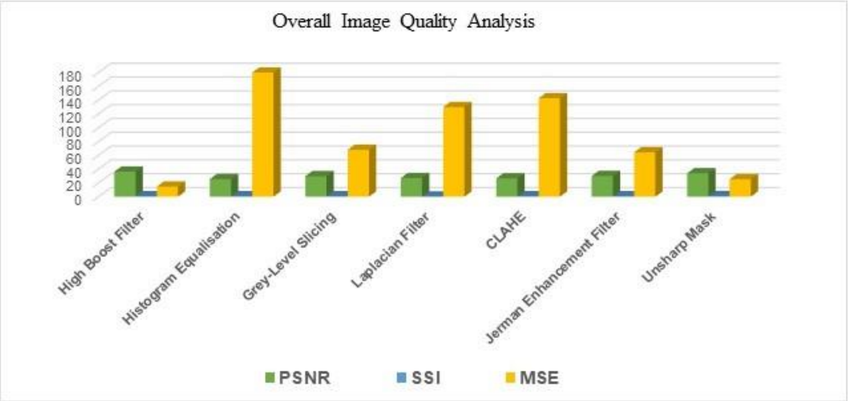


Fig. 8. Overall Image Quality Analysis with Enhancement Filters.

Exploiting hand prints apart from contact fingerprints can open up a new direction in contact-based biometrics. Since fingerprints are smaller in size and are more vulnerable to distortions due to contact pressure, wetness, scars, and finger marks, it would be better to incorporate handprints along with the fingerprints to cover a larger surface and contact area. In that sense, it requires a mechanism to treat those prints in terms of algorithm complexity and enhancement feasibility. From an algorithm perspective, the triangle and graph-based algorithm proposed in this work is capable of handling the bombardment of spurious minutiae in degraded prints by expanding Delaunay triangles and sub-graphs, thereby eliminating the presence of false minutiae as explained in Section 3.3. From the enhancement perspective, an optimised technique or a set of filters could be another initiative for image enhancement. If we can introduce an appropriate mechanism to address the severe degradation in contact handprints, then the prints can be successfully exploited in civilian applications like access control along with forensic tasks. Furthermore, since palmprints have already been in practice for legal claims, the investigation of appropriate enhancement filters for degraded palmprints can enhance the existing system's performance, and make it more reliable for legal outcomes.

When concerning the practical feasibility of using enhancement techniques, utilizing spatial-level filters may have a low computational cost compared to conventional frequency filters. For instance, Gabor filters incorporate ridge orientation and frequency information, leading to increased computational cost. Since the area of the palmprint is larger than the fingerprint, then exploiting spatial filters would be more practically feasible. In that sense, selecting an optimised technique can offer advantages, and this work explores identifying a set of filters that can be integrated with contact-based palmprint systems.

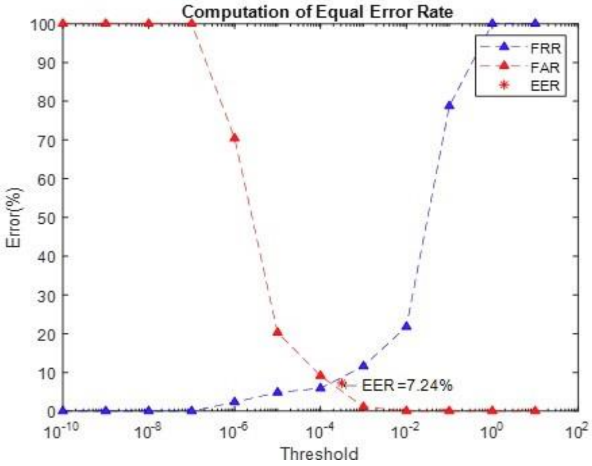


Fig. 9. EER using High boost Filter Enhancement

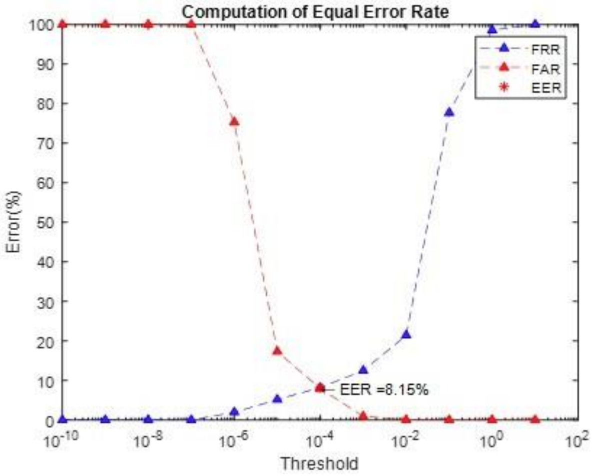


Fig. 10. EER using Unsharp Masking Enhancement

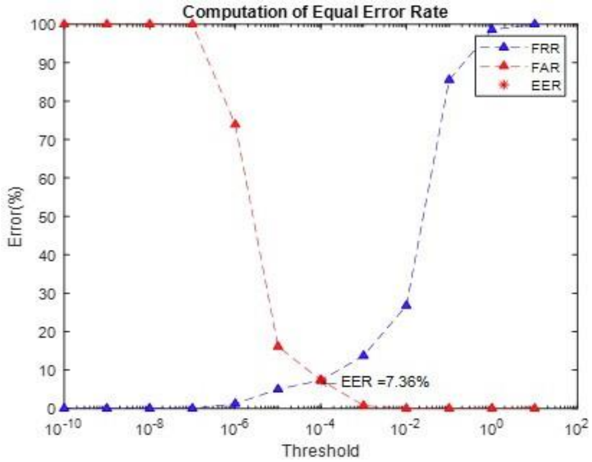


Fig. 11. EER using Jerman Enhancement

5. Conclusion

This study explores the potential employment of filters utilised in other applications in the enhancement of degraded contact-based palmprints' enhancement. Further, it outlines that they can preserve the quality of the image without losing their discriminatory features. From the analysis using enhancement filters in palmprint enhancement, the high boost filter exhibits a slight performance improvement with partially degraded palmprints. Furthermore, it exhibits the highest PSNR compared to other conventional techniques used in fingerprint enhancement. This pilot test aims to explore the potential of enhancement techniques without compromising the image quality in the palmprint system. This work limits the experiments within spatial-level filters, especially incorporating filters from the biomedical domain with biometric applications. However, there is an open investigation to explore various filters in other computer vision domains as well in the future.

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How to cite this paper: Akmal Jahan Mohamed Abdul Cader, "Quality Assessment of Degraded Palmprints Using Enhancement Filters", International Journal of Image, Graphics and Signal Processing(IJIGSP), Vol.16, No.5, pp. 62-74, 2024. DOI:10.5815/ijigsp.2024.05.05