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Image Enhancement of Palmprint Images Using High-Pass Filter and Fast Fourier Transform Methods

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Abstract

This study investigates the effectiveness of High-Pass Filter (HPF) and Fast Fourier Transform (FFT) techniques for enhancing palmprint image quality. The methodology encompasses preprocessing stages including image cropping, resizing to 256×256 pixels, grayscale conversion, and histogram equalization. Enhancement is subsequently performed using spatial-domain HPF with two coefficient variations (K=1 and K=0) and frequency-domain FFT with three distinct high-pass filters: Ideal High-Pass Filter (IHPF), Butterworth High-Pass Filter (BHPF), and Gaussian High-Pass Filter (GHPF). Experimental evaluation of 30 palmprint image samples utilizes Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) metrics. Results demonstrate that HPF with K=1 achieves superior performance with average MSE of 7.064544 dB and PSNR of 40.01314 dB. Among frequency-domain approaches, IHPF yields optimal results with average MSE of 9.354056 dB and PSNR of 38.537046 dB. The research contributes to biometric image processing through comparative analysis of spatial and frequency enhancement methods, with practical implementation via a MATLAB-based graphical interface.

***Keywords**: Palmprint recognition, image enhancement, high-pass filtering, fast Fourier transform, quality metrics, biometric systems*

1. Introduction

Palmprint biometrics has emerged as a robust identification modality due to its distinctive pattern characteristics, including principal lines, wrinkles, and texture features that exhibit high uniqueness and temporal stability[1], [2]. Compared to fingerprint recognition, palmprint systems offer larger surface area for feature extraction and demonstrate resistance to minor skin conditions [3]. However, image acquisition under practical conditions often introduces quality degradation through factors such as uneven illumination, sensor noise, motion artifacts, and low contrast, which adversely impact subsequent feature extraction and matching accuracy [4].

Image enhancement techniques serve as essential preprocessing components to mitigate these quality limitations. These methods aim to improve visual perception and optimize images for automated processing without altering their fundamental information content [5]. Two primary approaches dominate enhancement methodologies: spatial-domain techniques that operate directly on pixel intensity values, and frequency-domain methods that transform images to spectral representations for selective frequency manipulation [6].

In the spatial domain, High-Pass Filtering (HPF) represents a fundamental sharpening approach that emphasizes high-frequency components corresponding to edges and fine details through convolution operations with specifically designed kernels [7]. Conversely, frequency-domain techniques leverage Fourier transforms to separate image content into spectral components, enabling targeted modification of frequency bands before reconstruction to the spatial domain [8].

Previous research has explored various enhancement strategies for biometric images. Palanikumar et al. [9] employed Discrete Curvelet Transform for palmprint quality improvement, while Siregar and Aryanta [10] evaluated frequency-domain restoration techniques for medical imaging applications. Despite these contributions, a comprehensive comparative analysis between spatial-domain HPF and frequency-domain FFT specifically tailored for palmprint enhancement remains insufficiently addressed in current literature.

This study addresses this research gap through three principal objectives: (1) Implementation and validation of HPF and FFT methodologies for palmprint quality enhancement, (2) Comparative performance evaluation using established objective quality metrics, and (3) Development of an interactive application framework to demonstrate practical implementation viability.

2. Methodology

The research employs an experimental methodology with systematic workflow comprising data preparation, preprocessing, enhancement implementation, quality assessment, and application development stages.

2.1 Data Preparation

The experimental dataset comprises 30 palmprint images acquired in BMP format with Region of Interest (ROI) extraction through manual cropping to isolate central palm regions while excluding finger areas. All samples exhibit normal physiological conditions without visible contamination, oil residues, or scar tissue that might compromise enhancement evaluation.

2.2 Preprocessing Pipeline

Standardized preprocessing ensures consistent input characteristics across all test images:
1) Dimensional Normalization: Uniform resizing to 256×256 pixel resolution using bicubic interpolation for computational consistency.
2) Color Space Conversion: RGB to grayscale transformation via luminance weighting coefficients (0.299R + 0.587G + 0.114B) following NTSC standard.
3) Contrast Enhancement: Histogram equalization implementation to optimize intensity distribution across the available dynamic range.

2.3 Enhancement Techniques Implementation

Two distinct enhancement paradigms were implemented and comparatively evaluated:

1. Spatial-Domain High-Pass Filtering

Convolution operations employ 3×3 kernel matrices with coefficient configurations:
Sharpening configuration (K=1):

$$\begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix} \quad (1)$$

Edge detection configuration (K=0):

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \quad (2)$$

2. Frequency-Domain Fourier Processing

Fast Fourier Transform converts spatial images to frequency representations for spectral filtering:
deal High-Pass Filter (IHPF) with abrupt cutoff at $D_0 = 5$:

$$H(u,v) = \begin{cases} 0 & if\ D(u,v) \le D_0 \\ 1 & if\ D(u,v) \le D_0 \end{cases} \quad (3)$$

Second-order Butterworth High-Pass Filter (BHPF) with gradual transition:

$$H(u,v) = \frac{1}{1+[D_0/D(u,v)^4} \quad (4)$$

Gaussian High-Pass Filter (GHPF) with exponential roll-off:

$$H(u,v) = 1 - e^{-D^2(u,v)/2D_0^2}$$

2.4 Performance Quantification

Objective quality assessment utilizes established metrics:
Mean Square Error (MSE): Quantifies pixel-wise deviation between processed (g) and reference (f) images:

$$MSE = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[f(x,y) - g(x,y)]^2 \quad (5)$$

Peak Signal-to-Noise Ratio (PSNR): Logarithmic representation of signal fidelity relative to maximum intensity:

$$PSNR = 10.log_{10}\left(\frac{255^2}{MSE}\right) \quad (6)$$

2.5 Application Development

Interactive implementation was achieved through MATLAB App Designer, incorporating modular components for image import, parameter configuration, visual comparison, and metric computation functionalities.

3. Results and Analysis

3.1 Preprocessing Outcomes

Preprocessing transformations successfully standardized image dimensions and enhanced contrast characteristics. Histogram equalization effectively redistributed intensity values, improving visibility of principal lines and texture details essential for biometric feature extraction.

3.2 Spatial Filter Performance

Quantitative evaluation reveals significant performance disparity between HPF configurations (Table 1). The K=1 kernel produces superior enhancement with substantially reduced reconstruction error and improved signal fidelity.

Table 1: Spatial Filter Quantitative Performance

Configuration	MSE (dB)	PNSR (dB)
HPF (K=1)	7.064544	40.01314
HPF (K=0)	57.147663	3056372

Visual inspection confirms that the K=1 configuration enhances edge definition while preserving overall intensity distribution, whereas K=0 exhibits excessive high-frequency amplification introducing artificial artifacts that degrade perceived quality.

3.3 Frequency Filter Evaluation

Frequency-domain approaches demonstrate varying characteristics (Table 2). IHPF achieves optimal balance between detail enhancement and noise suppression, while BHPF and GHPF provide smoother transitions with moderate sharpening effects.

Table 2: Frequency Filter Quantitative Performance

Filter Type	MSE (dB)	PSNR (dB)
IHPF	9.354056	38.537046
BNPF	12.228967	37.33549
GHPF	11.978327	37.384943

Spectral analysis reveals IHPF's binary cutoff characteristic produces crisper edge transitions, though occasional ringing artifacts appear near high-contrast boundaries. Butterworth and Gaussian implementations offer gradual attenuation that reduces such artifacts at the expense of minor sharpness reduction.

3.4 Comprehensive Comparative Analysis

Comprehensive comparison across 30 test samples establishes HPF (K=1) as consistently superior across both evaluation metrics. Frequency-domain methods demonstrate competitive performance, with IHPF marginally outperforming other spectral approaches. Representative performance data subsets are presented in Tables 3 and 4.

Table 3: Representative MSE Comparison (Subset)

Sample	HPF K=1	HPF K=0	IHPF	BHPF	GHPF
1	7.304	57.830	12.190	15.049	14.989
2	8.263	55.790	8.369	9.731	10.884
15	4.781	56.940	9.890	12.076	12.495
30	5.742	57.584	8.467	11.975	12.721

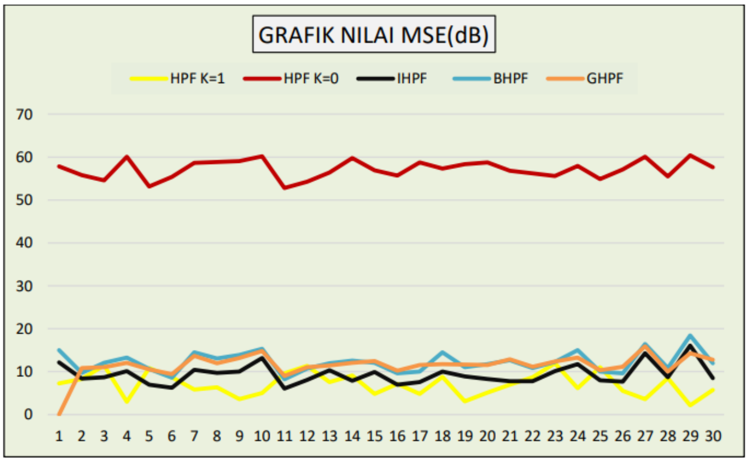

Fig 1: MSE Value Chart

Table 4: Representative PSNR Comparison (Subset)

Sample	HPF K=1	HPF K=0	IHPF	BHPF	GHPF
1	39.495	30.509	37.271	36.356	36.373
2	38.960	30.665	38.904	38.250	37.763
15	41.336	30.577	38.179	37.312	37.163
30	40.540	30.528	38.853	37.348	37.086

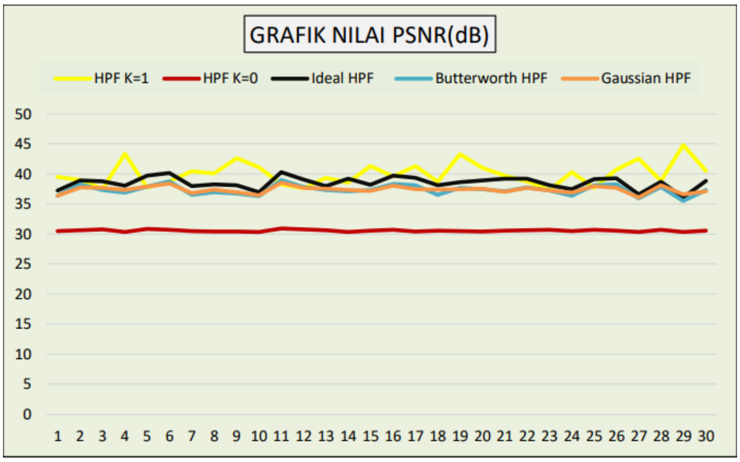

Fig 2: PSNR Value Chart

3.5 Application Implementation

The developed GUI application successfully integrates all methodological components within an intuitive interface. Functionality validation through systematic testing confirms robust operation across image import, parameter adjustment, processing execution, and results export capabilities.

4. Discussion

Experimental outcomes demonstrate distinct advantages of spatial-domain HPF with optimized kernel coefficients for palmprint enhancement applications. The K=1 configuration's superior performance originates from balanced coefficient design that amplifies high-frequency components while maintaining low-frequency integrity. This preserves overall image structure while enhancing discriminative features crucial for biometric recognition algorithms.

Frequency-domain methods offer alternative enhancement strategies with particular advantages for specific degradation types. IHPF's binary cutoff proves effective for images with moderate noise levels, while BHPF and GHPF provide preferable alternatives for noisier inputs through gradual frequency transitions. The consistent performance gap between spatial and frequency approaches suggests domain-specific characteristics of palmprint images favor direct pixel manipulation for quality enhancement tasks.

Practical implementation considerations include computational requirements, with spatial filtering demonstrating lower complexity than Fourier-based approaches requiring domain transformations. However, frequency methods enable more sophisticated noise modeling and selective enhancement capabilities potentially valuable for challenging acquisition conditions. The developed application framework successfully bridges theoretical methodology with practical implementation, offering researchers and practitioners accessible tools for palmprint enhancement experimentation.

5. Conclusion and Future Work

This research comprehensively implements and evaluates multiple enhancement methodologies for palmprint images. Key findings include:

1. Spatial-domain High-Pass Filtering with K=1 coefficients achieves optimal enhancement with average MSE of 7.064544 dB and PSNR of 40.01314 dB.
2. Frequency-domain processing using Ideal High-Pass Filter provides competitive alternative with average MSE of 9.354056 dB and PSNR of 38.537046 dB.
3. The developed MATLAB application enables practical implementation and comparative analysis of enhancement techniques.
4. These results advance biometric image processing methodology through systematic comparison of spatial and frequency enhancement approaches. The demonstrated techniques effectively improve feature visibility for subsequent recognition stages while maintaining computational efficiency.

Future investigations could explore several promising directions: (1) Hybrid approaches combining spatial and frequency techniques for synergistic enhancement, (2) Adaptive parameter optimization based on image content characteristics, (3) Integration with deep learning enhancement methods for further performance improvement, (4) Extension to multi-spectral palmprint imaging, and (5) Real-time implementation for practical biometric systems.

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