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Efficient Performance Analysis of Image Enhancement Filtering Methods Using MATLAB

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Abstract*: Image enhancement is both an art and a science, playing a pivotal role in enhancing the quality of high-resolution images like those captured by digital cameras. Its primary goal is to unveil hidden details within an image and augment the contrast in images with low contrast. This method provides a range of options for enhancing the visual appeal of images, making it a vital tool in various applications that encounter challenges such as noise reduction, degradation, and blurring. In this paper, we implemented frequency-domain low-pass filters, including the ideal low-pass filter, the Butterworth low-pass filter, and the Gaussian low-pass filter, with execution time analysis using MATLAB. The Butterworth low-pass filter gave better results than the other two with less execution time.

Keywords*: MSE, PSNR, Image Enhancement, Frequency Domain, Low Pass Filters, Image Processing, Execution Time.

I. INTRODUCTION

Image processing in the medical domain plays a critical role in diagnosis and decision-making. For the automation of medical diagnosis, images are captured and processed through various computations to provide an earlier and faster diagnosis of medical issues. With the development of new technologies, the process of computing and analysis has expanded from constrained remote processing to worldwide monitoring. In the area of medical diagnosis, this is rapidly developing in many folds due to the criticality in data processing and the demand for faster and accurate decisions [1] [2] [3] [4]. Image processing is a rapidly evolving field at the intersection of computer science, mathematics, and engineering. It involves the manipulation, analysis, and interpretation of digital images to extract meaningful information or enhance their visual quality. In today's digital age, image processing plays a crucial role in a wide range of applications, from medical imaging and remote sensing to entertainment and artificial intelligence [5]-[8]-[10]. image processing deals with the transformation of images through algorithms and mathematical operations. These images can be photographs, medical scans, satellite images, or even digital art. The primary goal is to improve the quality of an image, extract useful information, or make it more suitable for a specific application [9]-[7]. Basic Image Processing Operations: Image processing encompasses a broad spectrum of operations, including image enhancement. This involves improving the visual quality of an image by adjusting parameters such as brightness, contrast, and sharpness. Techniques such as histogram equalisation and contrast stretching fall into this category.

Image Restoration: When images are degraded by factors such as noise, blur, or compression, image restoration techniques are employed to recover the original information. Deconvolution is an example of a restoration technique. Image Segmentation**:** Image segmentation divides an image into regions or objects of interest. It's crucial for object recognition, medical image analysis, and scene understanding.

Image Compression: Image files can be pretty significant, especially those with high resolution. Compression techniques, such as JPEG and PNG, reduce file size while maintaining acceptable image quality. Feature Extraction: This involves identifying and extracting meaningful features from an image, such as edges, corners, textures, or shapes. Feature extraction is fundamental for pattern recognition and machine learning applications[12].

Image registration aligns multiple images, often from different sources or periods, to facilitate comparative analysis and interpretation. It's used in medical image fusion, remote sensing, and creating panoramic images. Colour Image Processing: Many photos are in colour, and processing techniques are adapted to work with the colour channels. Colour correction, colorization, and colour-based object detection are some applications [11].

Applications of Image Processing: Image processing is ubiquitous in various fields. Medical Imaging: In radiology, image processing plays a crucial role in diagnosis through techniques such as CT scans and MRI. It's also used in image-guided surgeries and pathology [13].

Satellite and Remote Sensing**:** Analyzing satellite imagery aids in weather forecasting, land use planning, disaster management, and environmental monitoring [14] [15] [16]. Entertainment: Special effects in movies, video games, and virtual reality rely heavily on image processing techniques for realistic visuals. Security: Facial recognition, fingerprint analysis, and surveillance systems all utilise image processing for identification and tracking purposes. The automotive industry: Image processing is integral to autonomous vehicles for object detection, lane keeping, and traffic sign recognition. Artificial Intelligence: Convolutional Neural Networks (CNNs) have revolutionized image analysis, enabling machines to recognize objects, people, and even emotions in images. Astronomy: Image processing helps astronomers in analyzing astronomical images, detecting celestial objects, and studying the universe [17] [18].

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II. IMAGE ENANCEMENT METHODS

To filter an image in the frequency domain: Compute *F(u,v),* the DFT of the image. Multiply *F(u,v)* by a filter function *H(u,v).* Compute the inverse DFT of the result.

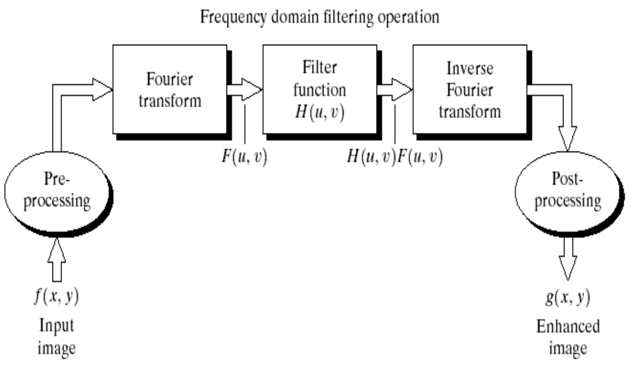

Fig. 1: Frequency Domain Block Diagram

A. Ideal Low Pass Filter

Smoothing Frequency Domain Filters: Smoothing is achieved in the frequency domain by eliminating high-frequency components. The basic model for filtering is:

$$G(u,v) = H(u,v)F(u,v)$$

where F(u,v) is the Fourier transform of the image being filtered and H(u,v) is the filter transform function Low pass filters – only pass the low frequencies, drop the high ones Simply cut off all high frequency components that are a specified distance D0 from the origin of the transform changing the distance changes the behaviour of the filter The transfer function for the ideal low pass filter can be given as

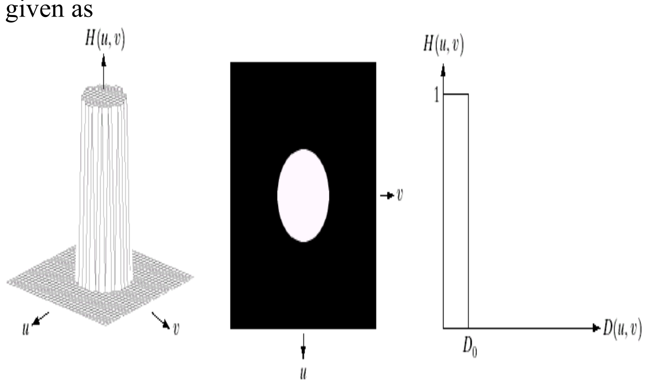

Fig. 2: Ideal low-pass filter

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

Where *D(u,v)* is given as:

$$D(u,v) = [(u - M/2)^2 + (v - N/2)^2]^{1/2}$$

B. Butterworth Low Pass Filter

The transfer function of a Butterworth low-pass filter of order *n* with cutoff frequency at distance D_0 from the origin is defined as

$$H(u,v) = \frac{1}{1 + [D(u,v)/D_0]^{2n}}$$

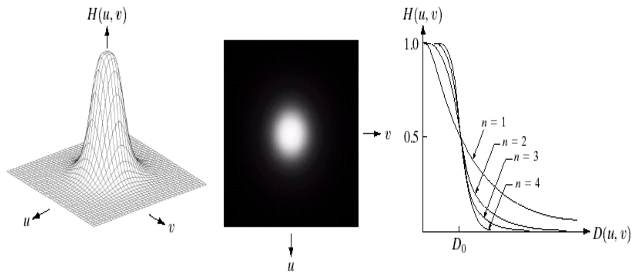

Fig. 3: Butterworth Low Pass Filter

C. Gaussian Low-pass Filters

The transfer function of a Gaussian low-pass filter is defined as:

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

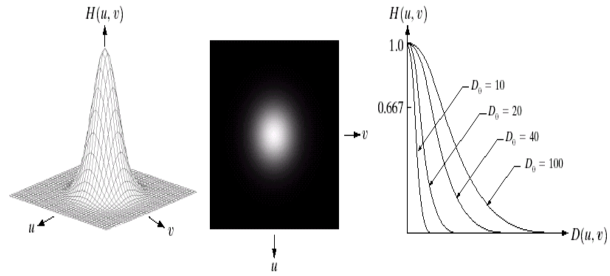

Fig. 4: Gaussian Low Pass Filter

III. PERFORMANCE ANALYSIS

Identify the efficient low-pass filter in the frequency domain using three filters. Namely, an ideal low-pass filter, a worth low-pass filter and a Gaussian low-pass filter. The metrics we use to identify the image quality are PSNR and MSE, peak signal to noise ratio, and mean square error [19] [20] [21].

A. Implementation

In this model of implementation.
Step 1: We have used six images for testing, namely one of a flower, two of Gaurav, three of a Cameraman, four of a Banana, five of Tamoto, and six of Nagaiah.
Step 2: Convert the colour image into a grey image.
Step 3: Applied to all three filters on that image.
Step 4: Calculated the PSNR value of both the original image and the output image.
Step 5: Calculated the MSE value of both the original image and the output image.
Step 6: Compared all the images based on their PSNR and MSE values.
Step 7: The Butterworth filter yields better results, as indicated by the PSNR and MSE values.

The following images have been tested, as have 25 other different photos. Here we have shown these six images. PSNR defines a ratio of signal strength over noise distortion strength. This is given as

$$PSNR(dB) = 10log_{10}\left(\frac{I_{peak}^2}{MSE}\right)$$

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Where I_{peak} is the peak value of the original sample, MSE reflect the average error in the filtered result as compared to the original image. This is defined by,

$$MSE = \frac{1}{MXN}\sum(f-\hat{f})^2$$

Here, f Is the actual test sample, and $\hat{f}$ Is the filtered output.

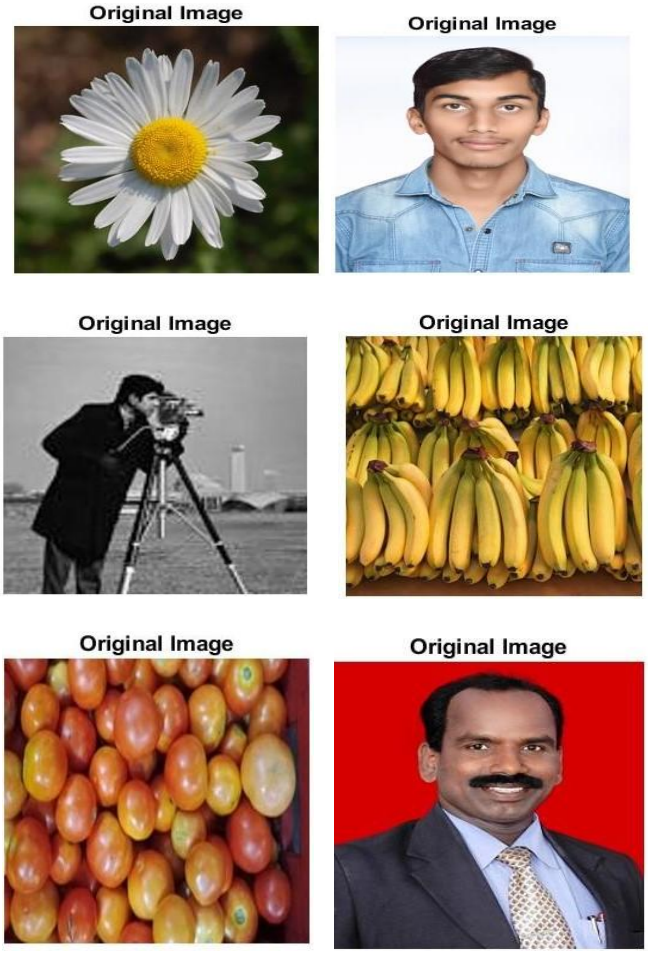
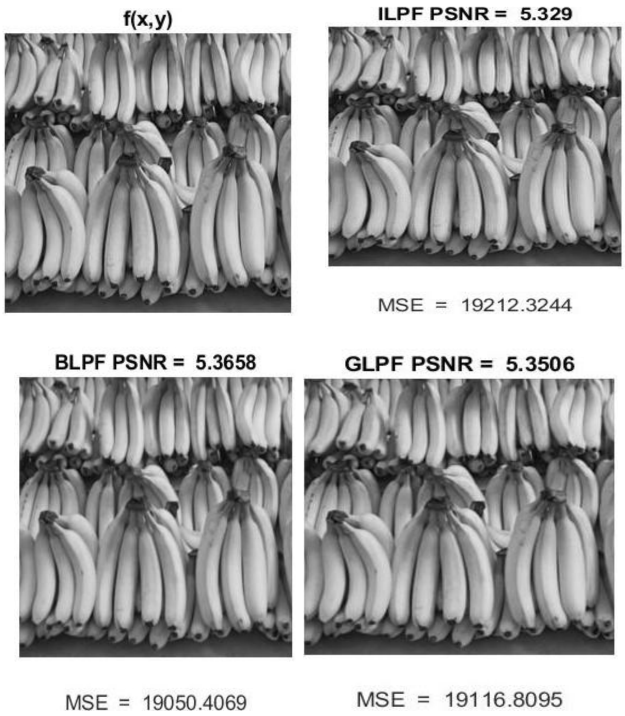


Fig. 5: Original Image and Filtered Images



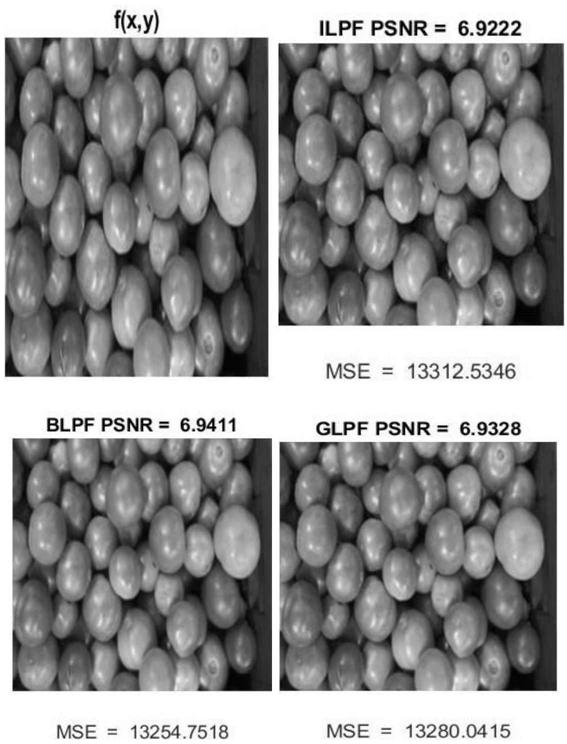


Fig. 6: All Output Images with PSNR and MSE

Table 1: Output Filtered Images with all Three Filter Outputs with PSNR Values

S NO	IMAGES	GLPF PSNR	BLPF PSNR	ILPF PSNR
1	flower	7.0522	7.0633	7.0368
2	Gaurav	2.0676	2.0706	2.0635
3	Cameraman	5.7388	5.7475	5.7273
4	Banana	5.3506	5.3658	5.329
5	Tamoto	6.9328	6.9411	6.9222
6	Nagaiah	8.3228	8.3347	8.3045

Table 2: Output Filtered Images with all Three Filter Outputs with MSE Values

		GLPF	BLPF	ILPF
S NO	IMAGES	MSE	MSE	MSE
1	flower	12919.777	**12886.95**	12965.79
2	Gaurav	40712.008	**40684.05**	40750.065
3	Cameraman	17482.248	**17447.29**	17528.582
4	Banana	19116.81	**19050.47**	19212.324
5	Tamoto	13280.041	**13254.75**	13312.535
6	Nagaiah	9642.8007	**9616.378**	9683.356

Table 3: Comparison of Filters: Three Filters with Execution Time

		GLPF	BLPF	ILPF
S No	Images	Execution time seconds	Execution time seconds	Execution time seconds
1	flower	0.0015	0.0032	0.0009
2	Gaurav	0.0008	0.0009	0.0010
3	Cameraman	0.0012	0.0013	0.0017
4	Banana	0.0008	0.0007	0.0008
5	Tamoto	0.0008	0.0008	0.0008
6	Nagaiah	0.0006	0.0007	0.0007

The importance of filters in Image analysis and medical applications is very significant. Frequency domain filters, such as low-pass filters, are effective in reducing high-frequency noise and interference. If images are noise-free, then the segmentation, feature extraction, feature selection, and classification processes are very effective—ideal low-pass filters are used in simulation and modelling in research work. Butterworth low-pass filters are used in audio equalisers. Gaussian low-pass filters are used in image smoothing and noise reduction in computer vision models. We can use it for signal de-noising in audio and sensor data.

IV. RESULTS AND DISCUSSION

We tested all three different filters with matrix PSR and MSE. The filtering process yielded a Butterworth low-pass filter, Which Provided better results compared to other filters. We have also tested the execution time for all three filters.

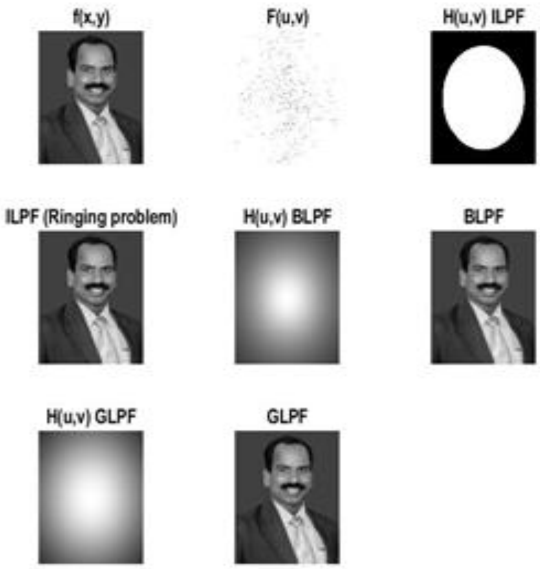


Fig. 7: All Filtered Outputs in Nagaiah image

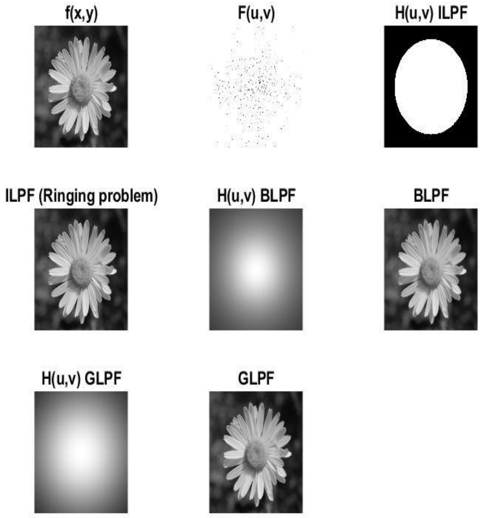


Fig. 8: All Filtered Outputs of Flower Image

V. CONCLUSION

The above work found that the Butterworth filter gives better results compared to the ideal low-pass and Gaussian low-pass filters. The PSNR value indicates that the image quality is good, and a low MSE value also means the image quality is good. These two parameters are inversely proportional. This will be very useful in image analysis, especially in medical imaging. Execution time is also a critical parameter in developing a system. Image quality is crucial, as it has a significant impact on subsequent processing steps, including image segmentation, feature extraction, classification, and final detection. Future scope includes further refinement of the filter design to improve PSNR values and enhance image quality.

DECALARION STATEMENT

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Availability of Data and Materials	Not relevant.
Authors Contributions	I am the sole author.

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