iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: VII Month of publication: July 2025

DOI: https://doi.org/10.22214/ijraset.2025.73143

Enhancement of Satellite Images by Smoothing and Sharpening Filters

Osho Chauhan[1], Dr. Jawahar Thakur[2]
[1]M.Tech, Research Scholar, Department of Computer Science, Himachal Pradesh University, Summerhill, Shimla, 171005
[2]Prof. Department of Computer Science, Himachal Pradesh University, Summerhill, Shimla 171005

Abstract : Satellite imagery plays a crucial role in a wide range of applications, including environmental monitoring, urban planning, and disaster management. However, raw satellite images often suffer from various distortions such as noise, low contrast, and blurring, which can reduce their interpretability and effectiveness. This dissertation explores the enhancement of satellite images using both smoothing and sharpening filters to improve their visual quality and feature clarity.

In the first phase, smoothing filters such as mean, Gaussian, median, and bilateral filters were applied to reduce noise and improve image uniformity. Each filter's performance was evaluated using metrics including entropy, Peak Signal-to-Noise Ratio (PSNR), and Edge Preservation Index (EPI). The bilateral filter demonstrated superior noise reduction while preserving important image edges.

In the second phase, sharpening filters such as Laplacian, unsharp masking, and high-pass filtering were implemented to enhance fine details and edges in the images. Performance metrics were again used to assess the impact of each method. Visual results and quantitative analysis revealed that sharpening significantly improved feature visibility after smoothing.

The experimental results confirm that a hybrid approach—combining appropriate smoothing followed by sharpening—yields enhanced satellite images with better clarity, noise suppression, and edge definition. This methodology contributes to more accurate analysis and interpretation of satellite data in practical applications.

I. INTRODUCTION

Satellite imagery refers to images of Earth or other planets collected by imaging satellites operated by governments or commercial organizations. These satellites are equipped with various sensors and cameras that capture data in multiple spectral bands, including visible, infrared, and radar. The data is then transmitted to ground stations, processed, and made available for a wide range of analytical and operational purposes. [1]

A. *Importance of Satellite Imagery*

Satellite imagery provides a unique and expansive view of Earth, enabling consistent and repetitive observation of large areas over time. This makes it an invaluable resource for understanding geographical, environmental, and climatic patterns. Unlike ground-based systems, satellites can cover remote or inaccessible regions, offering near real-time insights on a global scale.

B. *Key advantages of satellite imagery include*

- Wide-area coverage: Capture of vast geographical regions in a single shot.
- Temporal consistency: Frequent revisits for time-series analysis or monitoring.
- Multispectral capabilities: Ability to capture data beyond human vision (e.g., thermal, infrared, radar).[2]
- Cost-effectiveness**:** Reduces the need for on-ground surveys or manual inspections.

C. *Applications of Satellite Imagery*

Satellite imagery is used across numerous disciplines. Some of the major applications include:[3]

1) Environmental Monitoring
   - Deforestation tracking, air pollution analysis, glacier and ice cap observation, and ocean temperature monitoring.[4]

2) Urban Planning and Infrastructure
   - Detection of urban sprawl, land use classification, transportation network analysis, and construction project monitoring.

3) Agriculture and Crop Assessment
   - Monitoring crop health, estimating yield, detecting pest infestations, and managing irrigation using NDVI and other vegetation indices.
4) Disaster Management
   - Real-time tracking of floods, wildfires, hurricanes, and earthquakes. Satellite images assist in emergency response and post-disaster damage assessment.
5) Climate and Weather Forecasting
   - Observing cloud patterns, temperature changes, sea level rise, and precipitation systems.
6) Military and Strategic Use
   - Surveillance, border monitoring, and reconnaissance operations.
7) Geological and Mining Exploration
   - Identification of mineral-rich zones, fault lines, and geological structures.

D. Types of Image Enhancement Technique

Image enhancement techniques can be broadly divided into two main categories:[5]

1) Spatial Domain Techniques: These involve direct manipulation of image pixels in the spatial domain, often using mathematical operations applied to pixel values.
2) Frequency Domain Techniques: These involve manipulating the frequency components of an image by transforming the image into the frequency domain using techniques like the Fourier Transform.[6]

E. Types of filters used in image enhancemnt

1) Smoothing Filters (Blurring Filters): Smoothing filters are commonly used in image enhancement to reduce noise, remove fine details, or soften the image. These filters work by averaging the pixel values of the image, thereby blurring areas that contain sharp transitions or noise.[7]
2) Sharpening filters: Image sharpening is an effect applied to digital images to give them a sharper appearance. Sharpening enhances the definition of edges in an image. The dull images are those which are poor at the edges. There is not much difference in background and edges. On the contrary, the sharpened image is that in which the edges are clearly distinguishable by the viewer. We know that intensity and contrast change at the edge. If this change is significant then the image is said to be sharp. [8]

F. Role of Image Processing in Satellite Imagery

The enhancement of satellite images is a crucial step in improving the interpretability, accuracy, and usability of remote sensing data for applications such as urban planning, environmental monitoring, disaster assessment, and land cover classification. This study focused on enhancing satellite imagery through the implementation and evaluation of various **smoothing and sharpening filters**, with the aim of improving image clarity while preserving critical structural and textural information.[9]

1) Enhancement of Visual Quality
2) Noise Reduction and Deblurrin
3) Edge and Feature Detection
4) Preprocessing for Analytical Tasks
5) Data Compression and Restoration

II. LITERATURE REVIEW

Satellite image enhancement plays a pivotal role in improving the visual quality and interpretability of remotely sensed data. Over the years, researchers have proposed a variety of filtering techniques aimed at reducing noise, preserving edges, and enhancing fine details.

Smoothing filters such as the Mean, Gaussian, and Median filters are widely used to reduce image noise and suppress minor variations[10]. The Mean filter is simple but often blurs edges, while the Gaussian filter offers better edge preservation by applying a weighted average based on spatial distance. The Median filter performs particularly well for salt-and-pepper noise, preserving edges more effectively than linear filters (Gonzalez & Woods, 2018).

To counter the drawback of edge loss in traditional smoothing, Bilateral filtering[11] has gained popularity due to its edge-aware nature, which combines spatial closeness and pixel similarity, thus effectively reducing noise while preserving edge details (Tomasi & Manduchi, 1998).

On the other hand, sharpening filters such as the Laplacian, Unsharp Mask, and High-Boost filters are employed to enhance image contrast and emphasize edges. The Laplacian filter highlights rapid intensity changes but may amplify noise if not applied carefully. The Unsharp Mask subtracts a blurred version of the image from the original to improve edge clarity, and the High-Boost filter generalizes this by scaling the original image to further boost detail (Jain, 1989)

Recent stIudies suggest that hybrid approaches, combining both smoothing and sharpening filters, can yield superior results. For example, Bilateral filtering followed by Unsharp Masking balances noise reduction and edge enhancement, producing visually and quantitatively improved images (Kumar et al., 2021).

In summary, while individual filters have specific strengths, their combination—when properly tuned—can provide an optimal enhancement solution for satellite images, particularly when evaluated using metrics like PSNR, MSE, Entropy, and Edge Preservation Index (EPI).or

III. EVALUVATION METRICES FOR IMAGES

Edge Preservation Index for various smoothing filters

The Edge Preservation Index (EPI) is a crucial metric for evaluating how well an image enhancement technique retains edge information — a key factor in satellite image clarity. A higher EPI value signifies better edge retention, while a lower value indicates significant edge loss, often caused by over-smoothing[12]

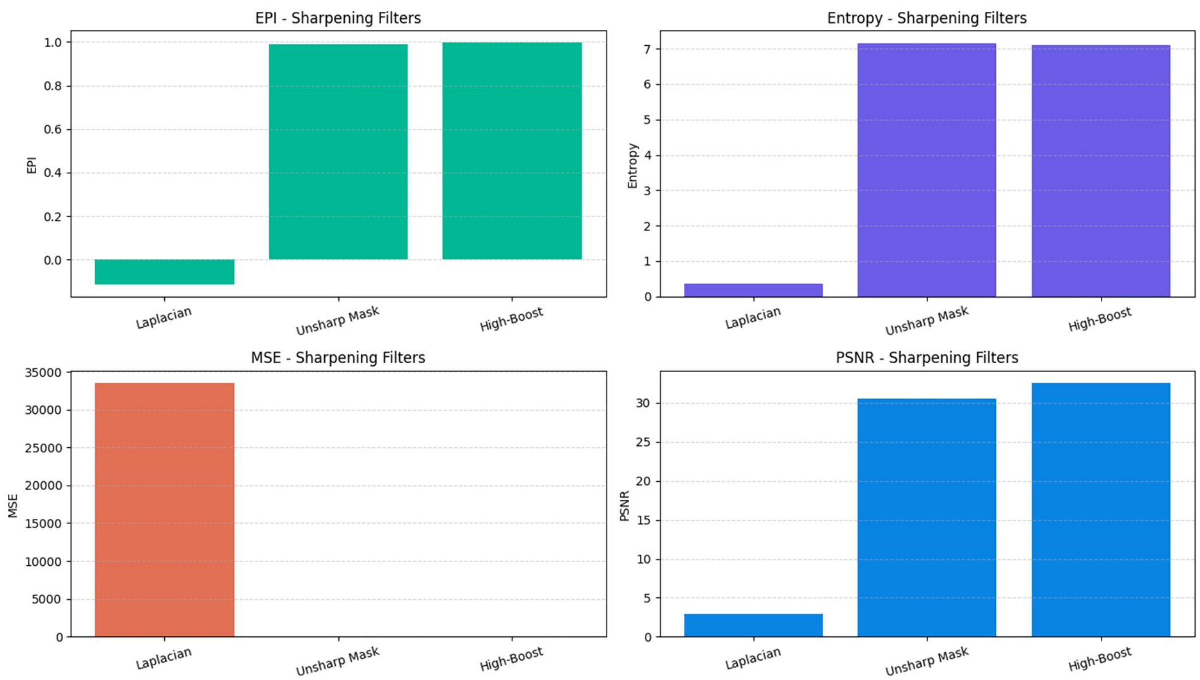
FILTER	EPI
Mean	0.077803
Median	0.269109
Gaussian	0.512235
Bilateral	0.92612

A. Performance Metric Table For Sharpening Filter

By applying various sharpening filters to enhance satellite images by improving their clarity, contrast, and edge definition. While smoothing filters are primarily used to reduce noise and blur, sharpening filters serve the opposite function — they enhance the high-frequency components of the image, making fine details and boundaries more distinct.

Filter	EPI	Entropy	MSE	PSNR (dB)
Laplacian	0.1140	0.3673	33,464.4414	2.8850
Unsharp Mask	0.9904	7.1495	57.2015	30.5567
High-Boost	0.9967	7.1035	36.4970	32.5082

B. Graphical Representation Of The Table



C. Hybrid Method To Enhance Filter Efficency

A hybrid filtering method refers to a combination of smoothing and sharpening techniques applied in a sequential or integrated manner to enhance image quality more effectively than using either filter alone. In satellite imagery, this approach is particularly useful because raw satellite images often contain noise due to atmospheric interference or sensor limitations, while also requiring clear and well-defined edges for accurate analysis of geographical features.The hybrid method typically begins with a smoothing filter such as a Gaussian, Median, or Bilateral filter to reduce unwanted noise or distortions. This step improves the uniformity of image regions but can result in the softening or loss of edge information. To counteract this, a sharpening filter like the Unsharp Mask, Laplacian, or High-Boost filter is applied[13]

The below table represents the efficiency of smoothing and sharpening filter when used in isolation and when used together

D. Performance Metrics Table For All Filters

Filter	EPI	Entropy	MSE	PSNR
Mean	0.4802	6.8829	266.2298	23.8782
Gaussian	0.811	6.9493	113.4557	27.5825
Median	0.6136	6.8696	244.8184	24.2424
Bilateral	0.9311	6.9914	47.7393	31.342
Laplacian	-0.114	0.3673	33464.44	2.885
Unsharp Mask	0.9904	7.1495	57.2015	30.5567
High-Boost	0.9967	7.1035	36.497	32.5082
Combined	0.9368	7.0039	35.3485	32.6471

E. Analysis of Filter Performance Based on Evaluation Metrics

The performance evaluation of various filters—smoothing, sharpening, and a hybrid approach—provides valuable insights into their impact on satellite image enhancement. Four key metrics were used for comparison: Edge Preservation Index (EPI)**,** Entropy**,** Mean Squared Error (MSE)**, and** Peak Signal-to-Noise Ratio (PSNR)**.**

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VII July 2025- Available at www.ijraset.com

F. Smoothing Filters

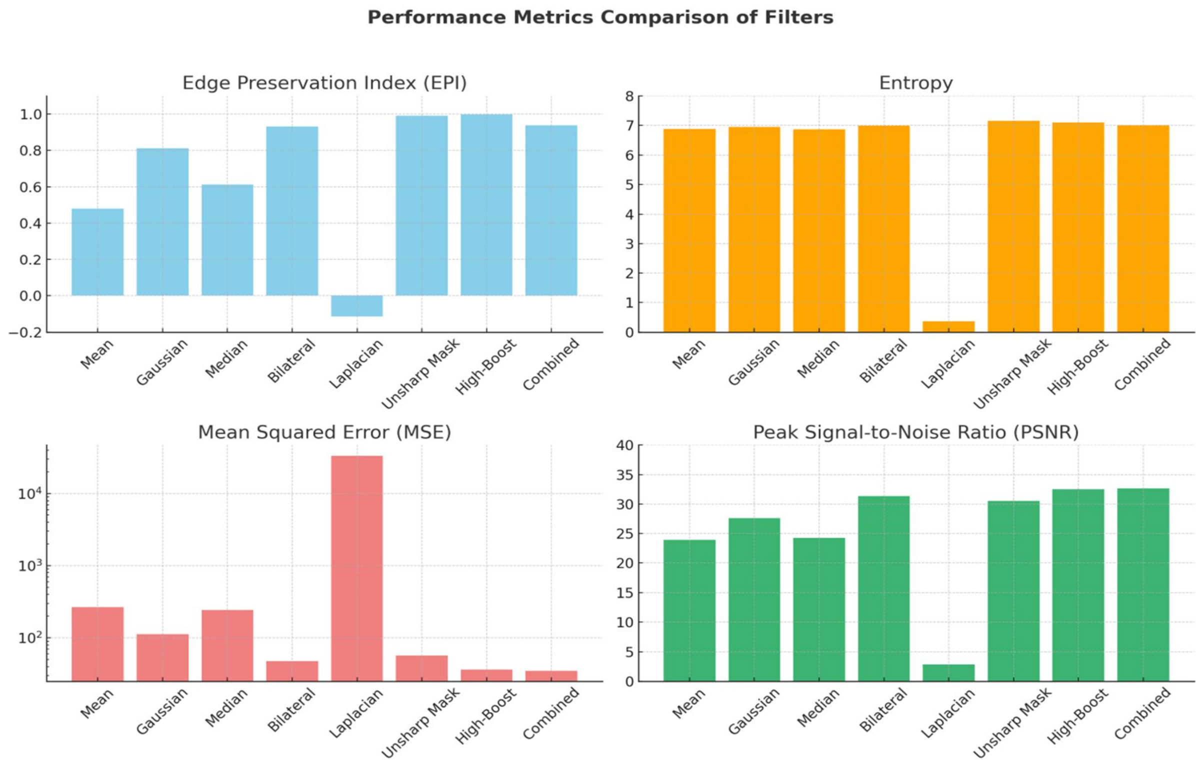
Among the smoothing techniques, the Bilateral filter stands out with an EPI of 0.9311, Entropy of 6.9914, and a relatively low MSE of 47.7393, resulting in a strong PSNR of 31.342 dB. This suggests that bilateral filtering not only reduces noise but also preserves edge information effectively. In contrast, the Mean and Median filters have lower EPI and PSNR values, indicating moderate smoothing but less effective detail preservation.

G. Sharpening Filters

Sharpening filters like Unsharp Mask and High-Boost produce excellent results. High-Boost filtering achieves the highest EPI (0.9967) and a very high PSNR (32.5082 dB) with low MSE, making it the most effective individual sharpening filter. Unsharp Mask also performs well, with slightly lower but still competitive values. However, the Laplacian filter performs poorly, with a negative EPI (-0.114), extremely high MSE (33,464.4414), and a very low PSNR (2.885 dB). This indicates that Laplacian filtering introduces significant distortion and is unsuitable in this context.

H. Hybrid Filter (Combined Bilateral + Unsharp Mask)

The Combined filter, which integrates Bilateral smoothing with Unsharp sharpening offers a balanced performance. It maintains a high EPI (0.9368) and Entropy (7.0039) while achieving the lowest MSE (35.3485) and the highest PSNR (32.6471 dB) across all filters. This demonstrates the strength of hybrid filtering—combining the noise-reduction capability of smoothing with the edge-enhancing power of sharpening—to produce high-quality, visually rich satellite images.



IV. FUTURE TRENDS

A. Future Trends

1) Deep Learning-Based Enhancement: Use of convolutional neural networks (CNNs), GANs, and transformers for learning complex enhancement patterns directly from data, outperforming traditional filters.[14]
2) Adaptive and Context-Aware Filtering: Development of smart filters that dynamically adjust their parameters based on local image features (e.g., texture, edge density, or noise level).
3) Hybrid Filtering Frameworks: Increased research on combining traditional and AI-based filters to balance speed, interpretability, and performance.

4) Real-Time Enhancement Using Edge Devices: Implementation of lightweight enhancement algorithms on drones, satellites, or IoT platforms for real-time image processing.
5) Spectral-Aware Enhancement for Multispectral/Hyperspectral Images: Techniques designed to enhance spatial quality while preserving spectral integrity across multiple bands.
6) Integration with Object Detection and Classification: Enhancement pipelines tailored to improve performance of downstream tasks like land cover classification, crop monitoring, and urban mapping.: Noise-Adaptive Multi-Scale Filtering: Application of wavelet or Laplacian pyramid-based filters to handle detail enhancement at various spatial scales.[15]
7) Explainable Filtering Techniques: Focus on creating interpretable enhancement models, especially in sensitive applications like environmental monitoring or defense.

V. CONCLUSION

The enhancement of satellite images is a crucial step in improving the interpretability, accuracy, and usability of remote sensing data for applications such as urban planning, environmental monitoring, disaster assessment, and land cover classification. This study focused on enhancing satellite imagery through the implementation and evaluation of various smoothing and sharpening filters, with the aim of improving image clarity while preserving critical structural and textural information.

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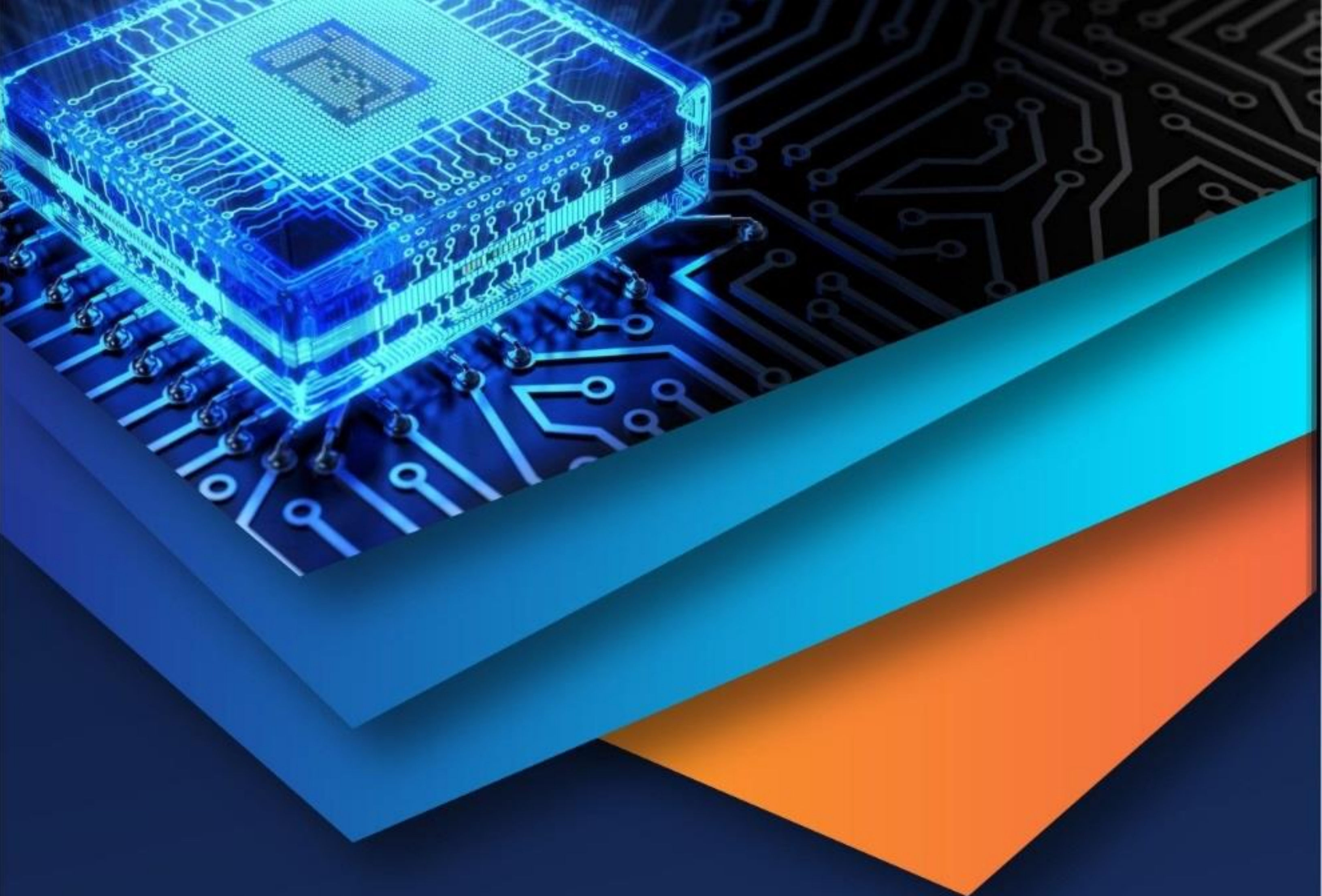

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