[Samsung PRISM] Preliminary Discussion

Model for Image Quality Assessment

Team

1. College Professor(s):
   - Dr. Jayanthi M G
   - Dr. Yasashwini
2. Students:
   1. Rahul Raj
   2. Syed Mohammad
   3. Sharvari Shetty
   4. Sahil A Gowda
   5. Gagan Gowda

3. Department: Computer Science and Engineering

Date: 19 Feb 2024

Model for Image Quality Assessment | Description

Problem Statement

Context

Image quality assessment is a crucial step in various computer vision applications, including image processing, machine learning, and visualization. The quality of an image can significantly affect the accuracy and reliability of tasks such as object detection, facial recognition, and medical diagnosis. In addition, high-quality images can provide a more engaging and satisfying user experience in applications like digital photography, video streaming, and virtual reality. Assessing image quality involves evaluating various aspects of an image, such as resolution, contrast, color accuracy, noise level, and compression artifacts. This process can help identify issues with the image, such as blur, overexposure, or lossy compression, which can then be addressed through image enhancement techniques.

Statement

Model for Image Quality Assessment

Work let Details

6	4	Abhishek Mishra Ankit Mishra Athira Menon
Duration (Months)	**Members Count**	Mentors

Expectations

Undertaken Tasks

- Understand problem statement thoroughly & it's final desired use-cases.
- Explore existing open solutions for Image Quality Assessment:
  - Based on Resolution, Contrast, Color Accuracy, Noise Level, Compression Artifacts (Blurriness, Blockiness), Focus, Exposure, Sharpness, Texture, etc
- Train the model to score image on given parameters.
- Possibly, improve image and hence score showing clear before, after in quality.
- Build PyQT based UI and Test it for high scale and maintain accuracy.

KPI

- Write Research Paper stating innovative methods for quality assessment.
- Scalable, Production Ready Script
- Accuracy >98% on any given sample.

Timeline

Kick Off
< 2^{nd} Month >

- Evaluation
- Design HDL & LDL

Milestone 1
< 4^{th} Month >

- Write Python Scripts for decided functions

Milestone 2
< 6^{th} Month >

- Apply batch & reduce time (benchmark against SOTA techniques)
- Completion of Research Paper

Meet Our Team

Cambridge Institute of Technology, North Campus
Department of Computer Science & Engineering

Gagan Gowda
5th Semester
(Computer Science)

Sahil A Gowda
Stream: Computer Science
(Computer Science)

Rahul Raj (Lead)
3rd Semester
(Computer Science)

Syed Mohammad
5th Semester
(Computer Science)

Sharvari Shetty
5th Semester
(Computer Science)

Model for Image Quality Assessment

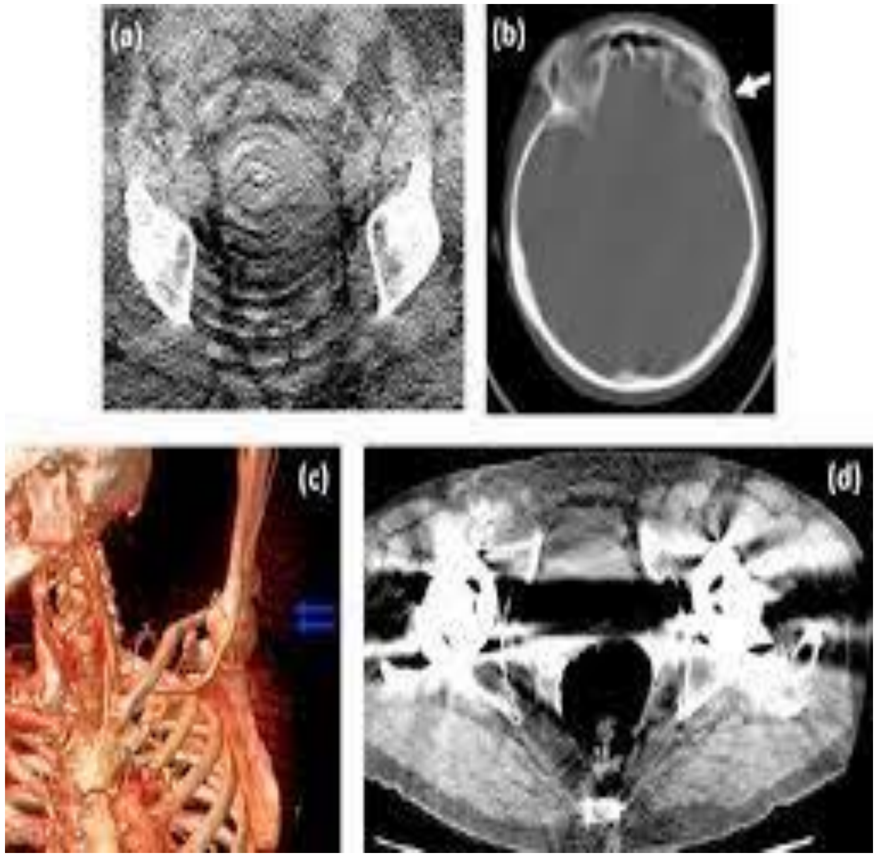
Understanding Problem Assessment

- Image quality assessment is crucial in various computer vision applications. It impacts the accuracy, reliability, and user experience in tasks such as object detection, facial recognition, and digital media consumption.
- Understanding IQA is key role in image processing, machine learning, and digital media consumption.
- Factors influencing image quality assessment.
  1. Resolution impacts image clarity.
  2. Contrast affects visibility of details.
  3. Color accuracy ensures faithful reproduction.
  4. Noise level indicates image cleanliness.
  5. Compression artifacts degrade image quality.
- Evaluate aspects like resolution, contrast, color accuracy, noise level, and compression artifacts.
- Identify issues such as blur, overexposure, or compression artifacts. Address issues using image enhancement techniques.

Applications of Image Quality Assessment

Medical Imaging Diagnosis

Ensures high-quality medical images for accurate diagnoses, where the clarity and fidelity of images are critical for identifying abnormalities. Whether it's X-rays, MRIs, or other imaging modalities, assessing and maintaining high image quality is fundamental for the success of medical imaging applications in healthcare.



Video Streaming Quality Control

Assessing and optimizing the quality of video frames to deliver a seamless and clear stream experience, particularly important for live broadcasts and video-on-demand services. By continuously evaluating the visual quality, streaming services can adapt and deliver the best possible resolution to users, preventing buffering and maintaining a smooth playback experience.

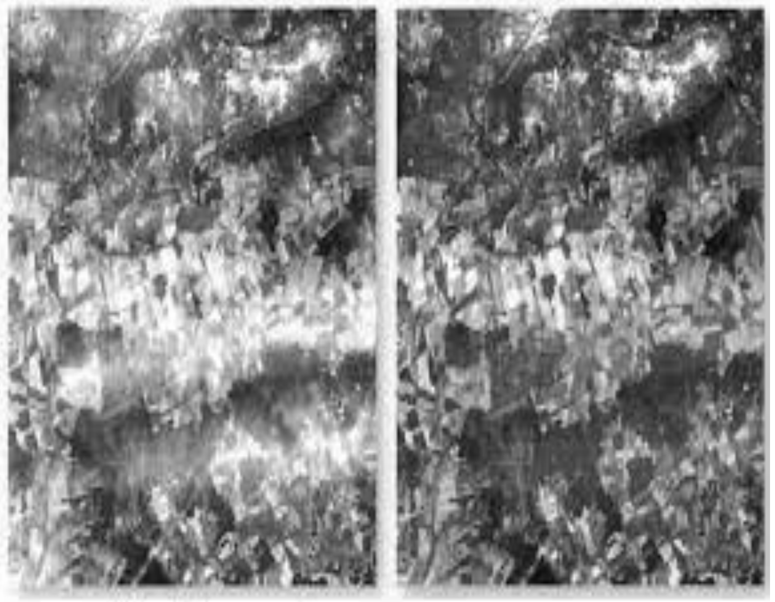
Biometric Recognition Systems

In facial recognition or fingerprint analysis, image quality assessment ensures that captured images meet standards for reliable identification, enhancing the accuracy of biometric systems, leading to more reliable identification in security systems, access control, and law enforcement applications.

Applications of Image Enhancement

Satellite Image Processing

Enhances satellite imagery for better interpretation of geographical features, aiding in applications like environmental monitoring, urban planning, and disaster management. This aids in automated classification of algorithms for monitoring the changes in land, identification of disasters and sustainable agricultural practices.

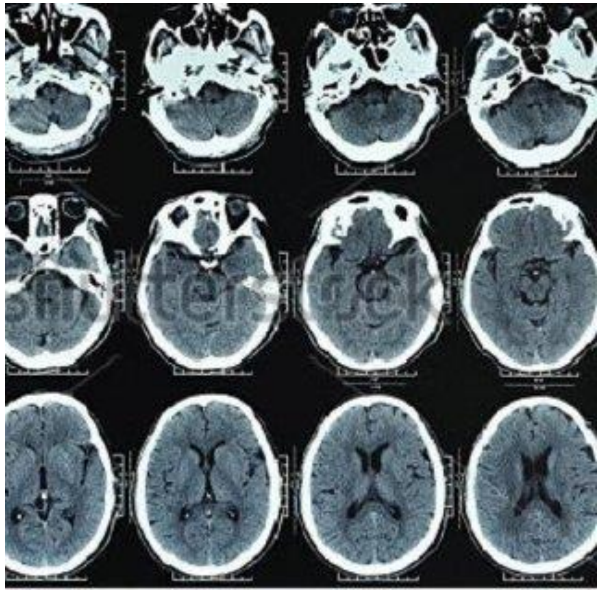


a. Before Enhancement b. After Enhancement

Security and Surveillance

Improves the clarity of surveillance camera footage, enabling better identification of individuals and objects, crucial for public safety and security purposes. Improves the clarity of facial features, aiding facial recognition algorithms in accurately identifying individuals in security systems, airports, and public spaces.

Digital Pathology in Healthcare



Enhances microscopic images of tissue samples, facilitating more accurate analysis by pathologists and aiding in the diagnosis of diseases like cancer. Enhanced pathology images contribute to better educational resources and research datasets. Researchers can extract more meaningful data from high-quality images, leading to advancements in understanding diseases and improving medical training

Image Quality Assessment Techniques

IQA Techniques

Peak To Noise Ratio(PSNR)

Peak Signal to Noise Ratio (PSNR) is a metric used to measure the quality of a reconstructed or processed image by comparing it to the original image. It quantifies the ratio of the maximum possible signal power to the power of the noise introduced during processing, providing a numerical value that indicates image fidelity.

$$\mathrm{PSNR}=20\log_{10}\left(\frac{\mathrm{MAX_f}}{\sqrt{\mathrm{MSE}}}\right)$$

Structural Similarity Index(SSIM)

SSIM, or Structural Similarity Index, is a metric used to measure the similarity between two images, typically an original and a compressed or processed version. It quantifies how well the processed image preserves the structural information and details of the original, aiding in assessing the quality of image compression and transmission.

$$SSIM(f,g)=l(f,g)c(f,g)s(f,g)$$

Where:

$$\begin{cases} l(f,g)=\dfrac{2\mu_f\mu_g+C_1}{\mu_f^2+\mu_g^2+C_1} \\ c(f,g)=\dfrac{2\sigma_f\sigma_g+C_2}{\sigma_f^2+\sigma_g^2+C_2} \\ s(f,g)=\dfrac{\sigma_{fg}+C_3}{\sigma_f\sigma_g+C_3} \end{cases}$$

Reference

https://www.scirp.org/journal/paperinformation?paperid=90911

IQA Techniques

Mean Square Error (MSE)

The Mean Structural Similarity Index Metric (MSSIM) is an average of SSIM scores computed across multiple local regions of an image, providing a comprehensive assessment of overall image quality. It offers a more robust and representative measure of similarity between the original and processed images, facilitating more accurate evaluations of image fidelity and perceptual quality

$$MSSIM(X,Y) = \frac{1}{M}\sum_{l=1}^{M} SSIM(xl, yl)$$

Human Visual Based Model (HVS)

In Image Quality Assessment (IQA), the Human Visual System (HVS) refers to the perceptual capabilities and limitations of the human eye and brain when viewing images. IQA methods based on HVS principles aim to mimic how humans perceive image quality, considering factors such as contrast sensitivity, spatial frequency response, and color perception. By incorporating models of the HVS into IQA algorithms, researchers can develop more accurate assessments of image quality that align with human perceptual judgments. Understanding the intricacies of the HVS is crucial for designing IQA techniques that effectively evaluate the visual fidelity of images

$$H(\rho) = \begin{cases} 0.05e^{\rho^{0.554}} & \rho < 7 \\ e^{-9\left|\log_{10}\rho - \log_{10}9\right|^{2.3}} & \rho \geq 7 \end{cases}$$

Reference

https://www.scirp.org/journal/paperinformation?paperid=90911

Deep Learning Based IQA Techniques

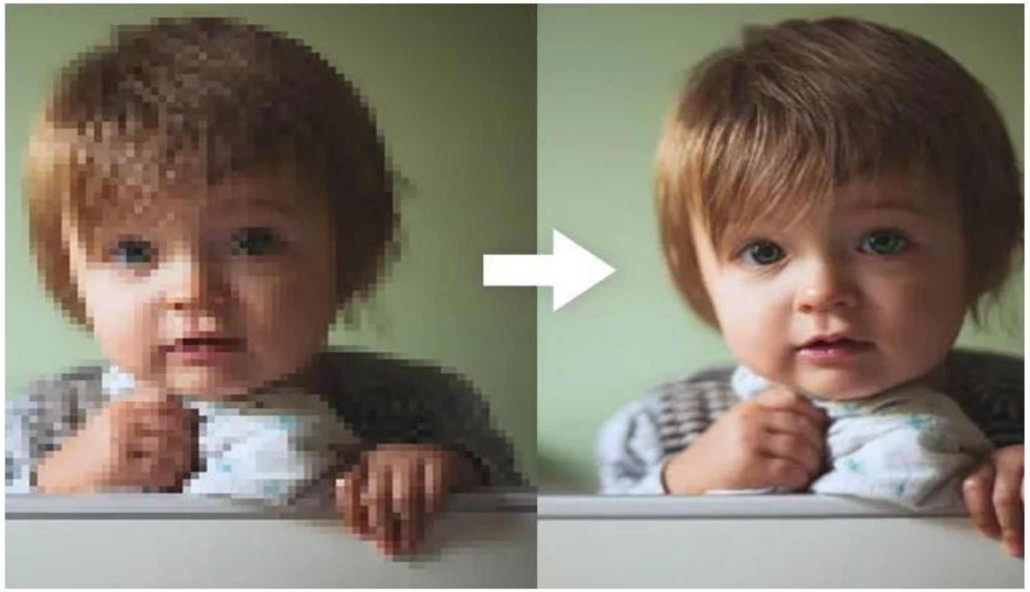
DEEP DE-BLUR

Deep deblurring is a technique used to remove blur from images, typically caused by motion blur or defocus blur.

- Deep Deblurring models often utilize CNN architectures such as U-Net or ResNet.
- The model is trained on the dataset of paired blurred and sharp images using techniques like stochastic gradient descent (SGD)

DEEP –SUPER RESOLUTION

- Deep super-resolution is a technique used to enhance the resolution of images, increasing their size and level of contextual information.
- Deep super-resolution models often employ CNN architectures, with variations such as
  - SRCNN (Super-Resolution Convolutional Neural Network)
  - SRGAN (Super-Resolution Generative Adversarial Network)
  - EDSR (Enhanced Deep Super-Resolution).

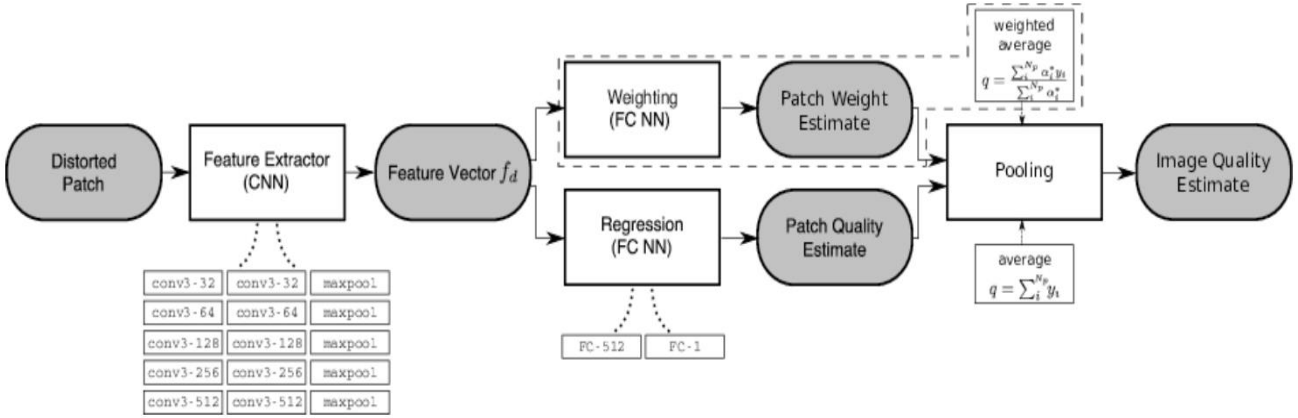


Super Resolution Results

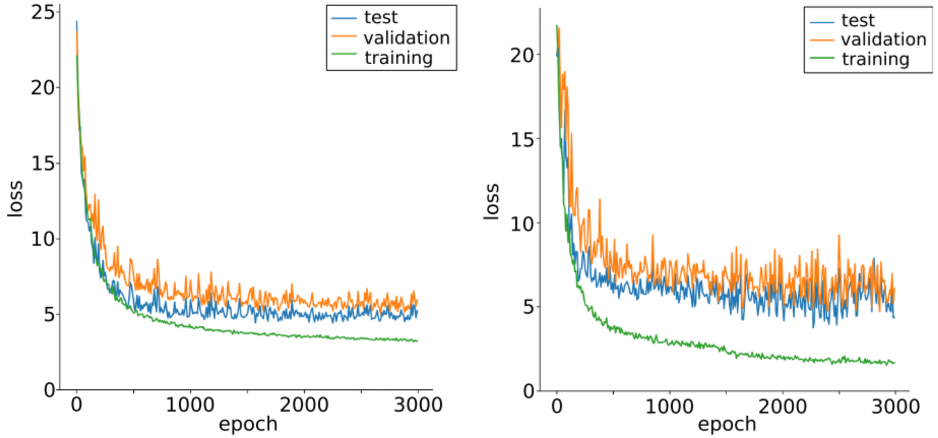
Deep Learning Based IQA Techniques

Deep-IQA / Deep-BIQA

We present a deep neural network-based approach to image quality assessment (IQA). The network is trained endto-end and comprises 10 convolutional layers and 5 pooling layers for feature extraction, and 2 fully connected layers for regression, which makes it significantly deeper than related IQA models. Unique features of the proposed architecture are that (1) with slight adaptations it can be used in a no-reference (NR) as well as in a full-reference (FR) IQA setting and (2) it allows for joint learning of local quality and local weights, i.e., relative importance of local quality to the global quality estimate, in an unified framework. Our approach is purely data-driven and does not rely on hand-crafted features or other types of prior domain knowledge about the human visual system or image statistics. We evaluate the proposed approach on the LIVE, CISQ and TID2013 databases as well as the LIVE In the Wild Image Quality Challenge Database and show superior performance to state-of-the-art NR and FR IQA methods. Finally, cross-database evaluation shows a high ability to generalize between different databases, indicating a high robustness of the learned features.



	IQM	LIVE LCC	LIVE SROCC	TID2013 LCC	TID2013 SROCC
Full-Reference	PSNR	0.872	0.876	0.675	0.687
	SSIM [8]	0.945	0.948	0.790	0.742
	FSIM_C [10]	0.960	0.963	0.877	0.851
	GMSD [11]	0.956	0.958	-	-
	DOG-SSIM [15]	0.963	0.961	0.919	0.907
	DeepSim [14]	0.968	**0.974**	0.872	0.846
	DIQaM-FR (proposed)	0.977	0.966	0.880	0.859
	WaDIQaM-FR (proposed)	**0.980**	0.970	**0.946**	**0.940**
No-Reference	BLIINDS-II[19]	0.916	0.912	0.628	0.536
	DIIVINE [18]	0.923	0.925	0.654	0.549
	BRISQUE [20]	0.942	0.939	0.651	0.573
	NIQE [21]	0.915	0.914	0.426	0.317
	BIECON [28]	0.962	0.961	-	-
	FRIQUEE [22]	0.930	0.950	-	-
	CORNIA [24]	0.935	0.942	0.613	0.549
	CNN [27]	0.956	0.956	-	-
	SOM [25]	0.962	**0.964**	-	-
	DIQaM-NR (proposed)	**0.972**	0.960	**0.855**	**0.835**
	WaDIQaM-NR (proposed)	0.963	0.954	0.787	0.761



(a) DIQaM-NR (b) WaDIQaM-NR

Reference

https://arxiv.org/abs/1612.01697

Other IQA Metrics

MSSIM

MSSIM (Mean Structural Similarity Index) is a method to measure how similar two images are by considering their luminance, contrast, and structure. It produces a score from -1 to 1, where 1 means identical images, 0 means no similarity, and -1 means complete dissimilarity. It's commonly used in image processing to evaluate the effectiveness of various techniques.

UIQI

UIQI (Universal Image Quality Index) is a metric used to quantify the quality of an image by comparing it to a reference image. It considers factors such as luminance, contrast, and structure to compute a score that represents the similarity between the two images. UIQI is used in image processing to evaluate the performance of image enhancement algorithms and to assess the visual quality of images.

FSIM

FSIM (Feature Similarity index) is another image quality assessment technique that evaluates the similarity between two images. It compares the structural information and features of the images to calculate a similarity score. FSIM is designed to be more robust than traditional methods like SSIM (Structural Similarity index) and MSSIM (Mean SSIM) in handling images with complex structures and textures. It's commonly used in tasks such as image quality assessment and image fusion.

$$\mathrm{MSSIM}(x,y) = \frac{2\mu_x\mu_y + c_1}{\mu_x^2 + \mu_y^2 + c_1} \cdot \frac{2\sigma_{xy} + c_2}{\sigma_x^2 + \sigma_y^2 + c_2}$$

$$\mathrm{FSIM}(x,y) = \frac{\sum f_x f_y + C_1}{\sqrt{\sum f_x^2 \sum f_y^2} + C_2}$$

$$\mathrm{UIQI}(x,y) = \frac{4\sigma_{xy}\mu_x\mu_y}{(\mu_x^2 + \mu_y^2)(\sigma_x^2 + \sigma_y^2)}$$

Reference

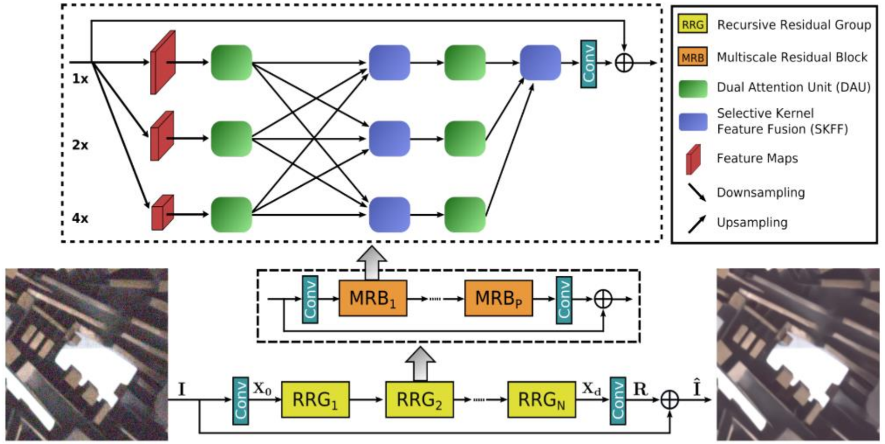
https://www.scirp.org/journal/paperinformation?paperid=90911

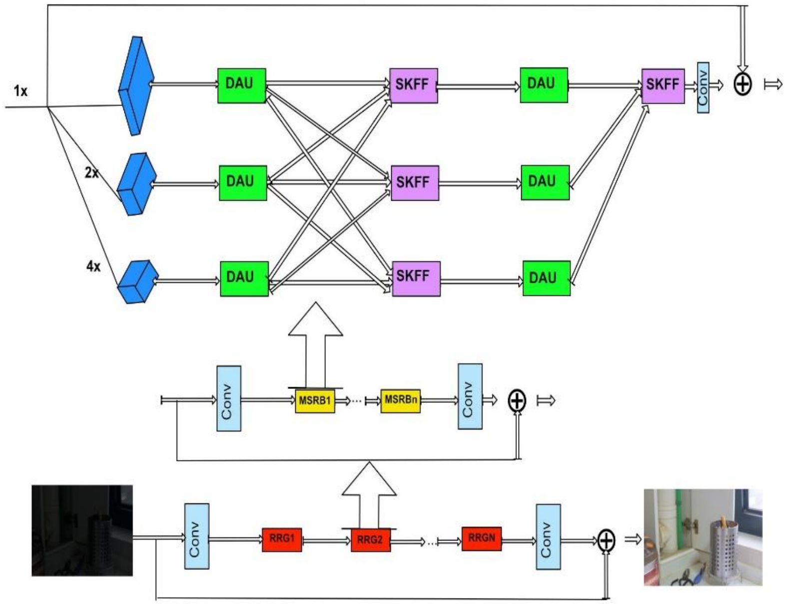
Image Enhancement Techniques

MIR-NET ARCHITECTURE

- MIRNet is a novel architecture designed for image restoration and enhancement tasks, prioritizing the preservation of high-resolution spatial details while incorporating rich contextual information.
- MIRNet utilizes Multi-scale Residual Block (MRB) to maintain spatially precise high-resolution representations, essential for preserving image details across different scales.
- Selective Kernel Feature Fusion (SKFF) is employed to facilitate information exchange across multi-resolution streams, enhancing the model's ability to leverage contextual information effectively.
- MIRNet Architecture used in various image processing tasks, including denoising, super-resolution, and image enhancement, as evidenced by experiments conducted on real image benchmark datasets.
- In this architecture it is emphasizing the significance of skip connections for convergence and minimizing training errors
- MIRNet employs attention mechanisms for multi-scale feature aggregation, allowing the model to focus on relevant information across different scales, further enhancing its performance.
- The potential applications of this Architecture in areas such as medical imaging, surveillance, and satellite imagery analysis.

LOW-LIGHT IMAGE ENHANCEMENT





Reference
https://www.researchgate.net/publication/347072050_Learning_Enriched_Features_for_Real_Image_Restoration_and_Enhancement

Transformers for Image Enhancement

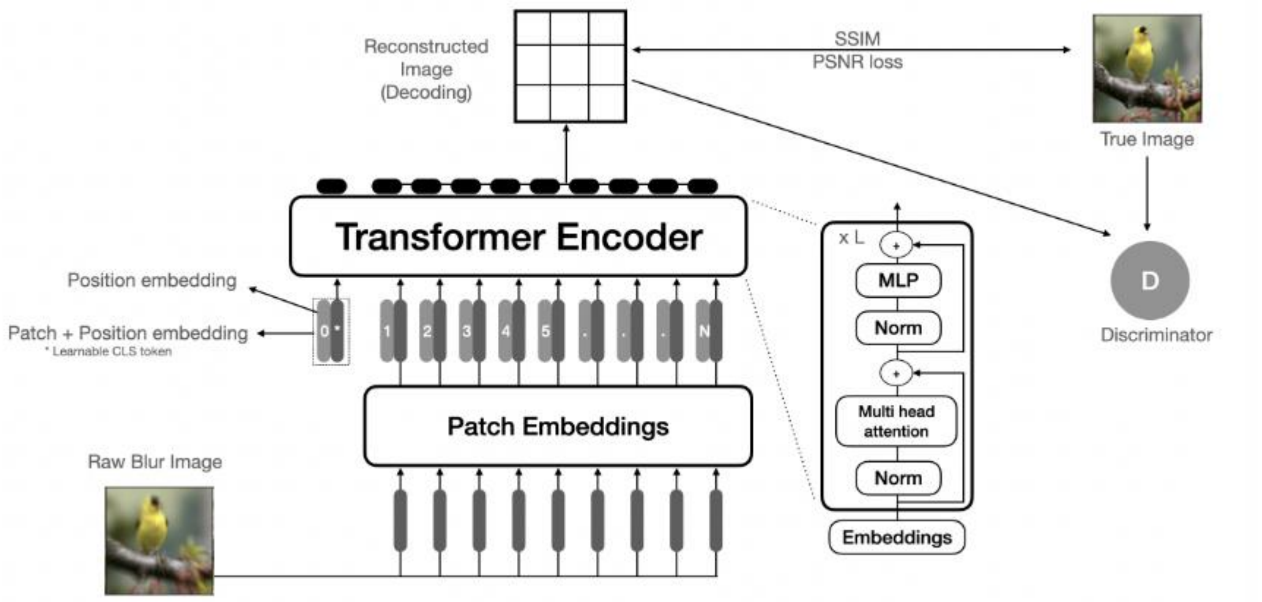
Enhanced Vision Transformer

Removing noise from images is a challenging and fundamental problem in the field of computer vision. Images captured by modern cameras are inevitably degraded by noise which limits the accuracy of any quantitative measurements on those images. In this project, we propose a novel image reconstruction framework which can be used for tasks such as image denoising, deblurring or inpainting. The model proposed in this project is based on Vision Transformer (ViT) that takes 2D images as input and outputs embeddings which can be used for reconstructing denoised images. We incorporate four additional optimization techniques in the framework to improve the model reconstruction capability, namely Locality Sensitive Attention (LSA), Shifted Patch Tokenization (SPT), Rotary Position Embeddings (RoPE) and adversarial loss function inspired from Generative Adversarial Networks (GANs). LSA, SPT and RoPE enable the transformer to learn from the dataset more efficiently, while the adversarial loss function enhances the resolution of the reconstructed images. Based on our experiments, the proposed architecture outperforms the benchmark U-Net model by more than 3.5% structural similarity (SSIM) for the reconstruction tasks of image denoising and inpainting. The proposed enhancements further show an improvement of ~5% SSIM over the benchmark for both tasks.

$$R(x) = xE_q(xE_k)^T$$

$$SA(x) = softmax(R/\sqrt{d_k})xE_v$$

Illustration of image after inpainting (left), reconstructed image (middle) and original image (right)



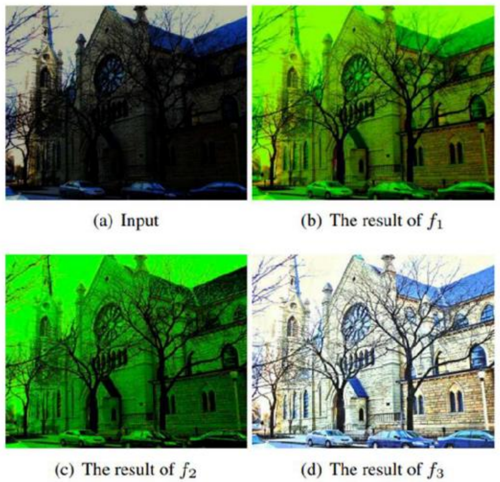
Denoising	U-Net	Vanilla ViT	LSA	SPT	RoPE
PSNR	21.90	27.10	27.03	27.23	**27.63**
SSIM	75.53%	78.95%	78.91%	79.96%	**80.86%**
NMSE	3.66%	1.04%	1.04%	0.99%	**0.90%**
Inpainting	**U-Net**	**Vanilla ViT**	**LSA**	**SPT**	**RoPE**
PSNR	21.90	24.69	24.75	24.79	**25.18**
SSIM	75.53%	79.18%	79.38%	79.81%	**80.81%**
NMSE	3.66%	2.30%	2.21%	2.21%	**2.04%**

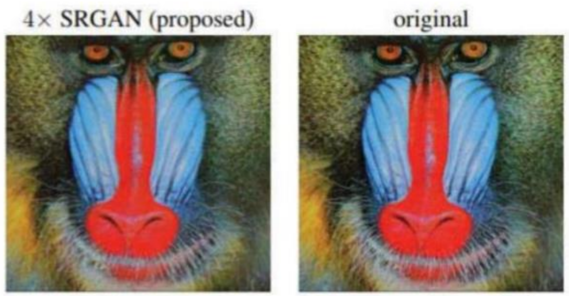
Reference

https://arxiv.org/abs/2307.05616

D-CNN (Deep Convolutional Neural Network) for Image Enhancement

The most significant area in imaging study and processing is image processing technique. The major goal is to improve quality images artificially through other means. The images that are obtained at times through certain mediums may end up distorted making the image unclear. One option to enhance the image quality is to change camera lens, which is costly. Thus, an alternative is required. A conventional neural network (CNN) may give priority to distinct aspects in an image and differentiate between them. A clear review of the literature on a few CNN-based picture enhancing techniques is carried out.





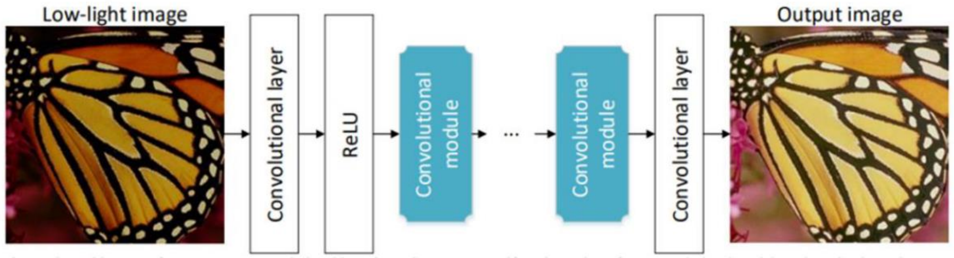
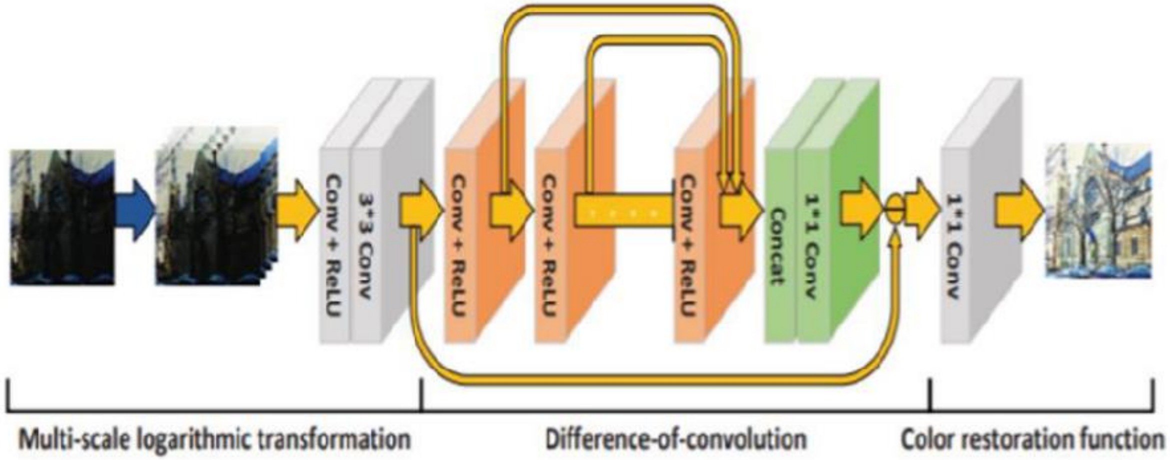
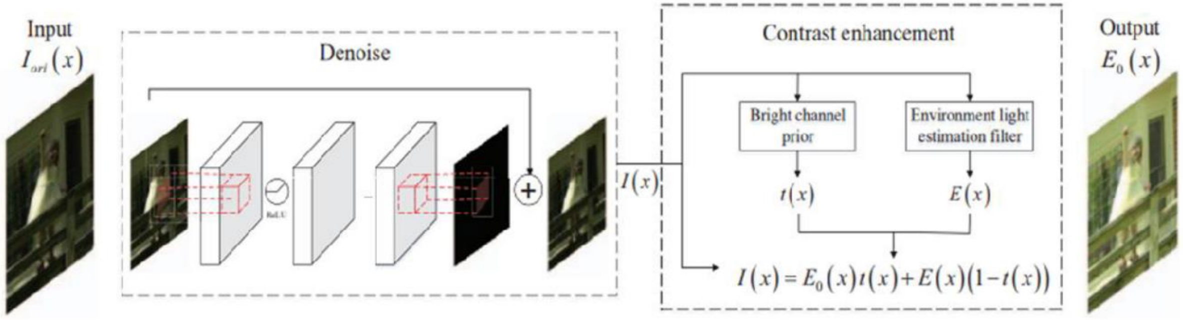


Figure 5: The LLCNN Architecture [8]



	Accuracy	Sensitivity	Specificity
Undenoised images	[88.04..89.83]	[87.37..93.68]	[83.68..91.23]
DCNN Denoised images	[90.04..94.25]	[88.04..96.52]	[84.5..96.02]
Wiener Filter Denoised images	[77.91..87.31]	[74.4..95.45]	[71.2..94.55]
Median Filter Denoised images	[73.04..88.08]	[65.13..94.10]	[70.6..94.71]



Reference
https://ijarsct.co.in/Paper2910.pdf
https://pdf.sciencedirectassets.com/280203/1-s2.0-S1877050922X00100/1-s2.0-S1877050922011814/main.pdf

Other Image Enhancement Techniques

Deep Learning-based Denoising

Description: Deep learning approaches, such as autoencoders or generative adversarial networks (GANs), are trained to remove noise from images while preserving image details and textures.

Accuracy: Deep learning-based denoising techniques often outperform traditional denoising methods, achieving high accuracy in noise reduction while minimizing the loss of image details

Contrast Limited Adaptive Histogram Equalization (CLAHE)

Description: CLAHE is an adaptive histogram equalization technique that enhances image contrast by redistributing pixel intensities locally.

Accuracy: CLAHE is highly effective in enhancing image contrast and improving visual quality, particularly in images with uneven illumination or low contrast regions.

Multi-Scale Retinex

Description: Multi-Scale Retinex is a non-linear image enhancement technique that simulates human visual perception by decomposing images into multiple scales and enhancing contrast and brightness at each scale.

Accuracy: Multi-Scale Retinex algorithms can achieve significant improvements in image quality, particularly in low-light conditions or images with uneven illumination.

Reference

https://www.nature.com/articles/s41598-023-4866

Image Distorting Algorithms

Different Noising Algorithms

Gaussian Noise : spatial filtering techniques such as Gaussian smoothing or bilateral filtering.

Poisson noise : Wiener filtering and Poisson Maximum Likelihood Estimation (PMLE)

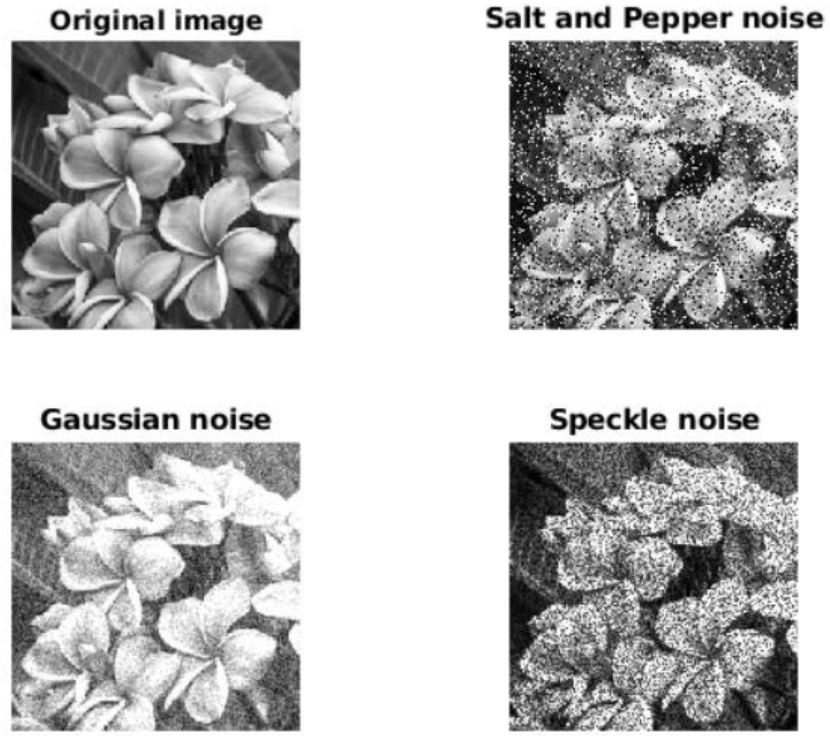
Salt and Pepper Noise:

Adaptive median filtering, morphological operations like erosion and dilation are also commonly used.

Speckle Noise

filtering, wavelet-based methods and adaptive filtering techniques are commonly used

.



Different Noising Algorithms

- Image denoising is the process of removing noise from images to improve clarity and quality using filtering or deep learning techniques.
- There are different types of Image Noising:
  - Gaussian Noise
  - Poisson Noise
  - Salt Pepper Noise
  - Speckle Noise
  - Exponential Noise
- These techniques to solve Image Denoising are classified into 2 Main Approaches:
  - Spatial Filtering Methods
  - Transform Domain Methods

Spatial Filtering Methods

These methods operate directly on the pixel values of the image.

They typically involve applying a filter or convolution kernel to each pixel or neighborhood of pixels to smooth out noise while preserving important image features.

Transform Domain Methods

These methods transform the image into a different domain, such as the frequency domain using techniques like Fourier transform or wavelet transform.

Denoising is then performed by modifying the transformed data and transforming it back into the spatial domain.

IMAGE WITH NOISE

IMAGE WITHOUT NOISE

Image Dimming Algorithm

- In image distorting algorithms, image dimming can refer to a specific type of manipulation where the overall brightness or luminance of the image is reduced. This effect can be achieved through various techniques within the algorithm, such as:

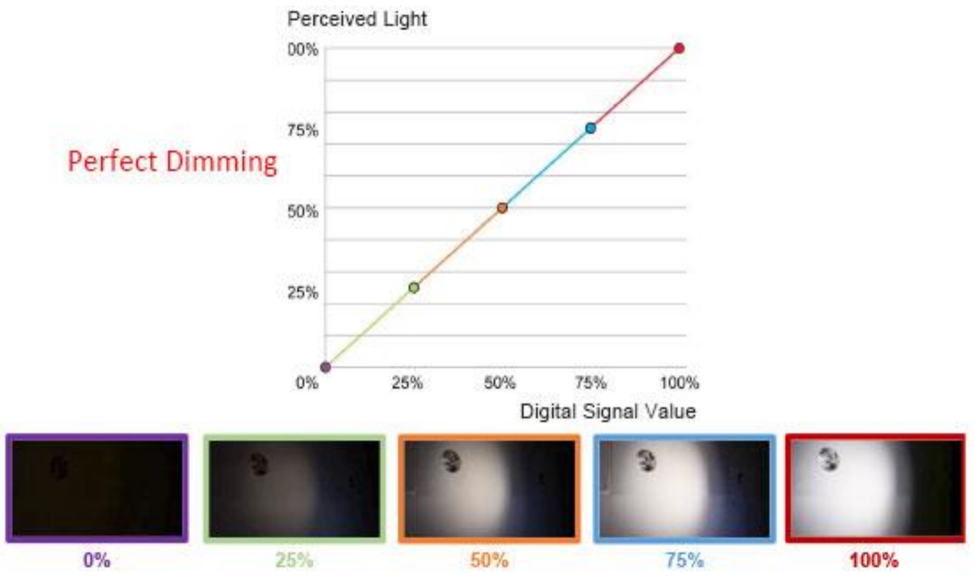
1. Brightness Reduction: One straightforward method is to simply decrease the brightness of all pixels in the image uniformly. This reduces the overall luminance, resulting in a dimmer appearance.
2. Exposure Adjustment: Similar to brightness reduction, exposure adjustment involves decreasing the exposure level of the image, which effectively dims the overall brightness.
3. Applying a Dark Overlay: Another approach is to overlay a semi-transparent dark layer over the image. By adjusting the opacity and intensity of this layer, the image can be dimmed while still retaining its original content.
4. Tonal Mapping: Tonal mapping techniques adjust the tonal distribution of an image, redistributing the brightness levels to achieve a desired effect. Dimming can be achieved by compressing the dynamic range of the image, reducing the contrast between lighter and darker areas.
5. Gamma Correction: Gamma correction alters the brightness levels of an image based on a nonlinear transformation. By adjusting the gamma value, the overall brightness can be dimmed or brightened.

Image Dimming Algorithm

LINEAR DIMMING

- Linear dimming is a straightforward technique where the brightness of an image is uniformly reduced by a constant factor across all pixels. It's called "linear" because the reduction in brightness is directly proportional to the original brightness of each pixel.
- Working :

1. Each pixel's brightness value is multiplied by a constant factor less than 1 to decrease its intensity.
2. This reduction is uniform across all pixels, meaning that every part of the image becomes darker by the same amount.
3. Linear dimming is a simple and quick way to adjust the overall brightness of an image but may result in loss of detail, especially in highlights and shadows

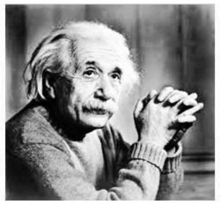


HISTOGRAM EQUALIZATION

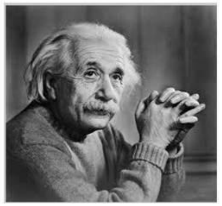
- Histogram equalization is a more sophisticated technique used to enhance the contrast and visibility of details in an image. Instead of uniformly dimming or brightening the entire image, histogram equalization redistributes the pixel intensities to make better use of the available dynamic range.
- Working :

1. First, a histogram of the image's pixel intensities is computed, showing the frequency of occurrence of each intensity level.
2. Then, the histogram is equalized by mapping the pixel intensities in such a way that the cumulative distribution function becomes more uniform.
3. This redistribution of pixel intensities typically results in improved contrast and visibility of details in the image. Histogram equalization is particularly useful for images with low contrast or uneven lighting conditions.

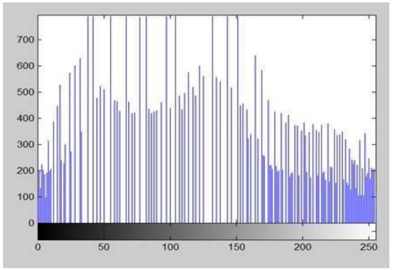
New Image



Old image



New Histogram



Old Histogram

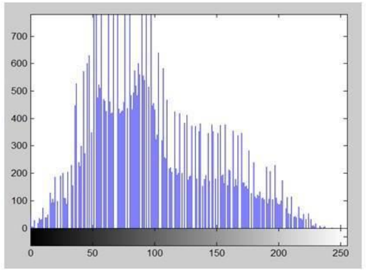


Image Dimming Algorithm

Brightness Adjustment

- Purpose: The purpose of brightness adjustment is to change the overall brightness of an image.
- Algorithm: This algorithm involves adding or subtracting a constant value to/from the intensity values of all pixels in the image.
- Operation: To increase brightness, a positive constant value is added to all pixel intensities, making the image brighter. Conversely, to decrease brightness, a negative constant value is added, making the image darker.
- Effect: Brightness adjustment is a simple and intuitive way to control the overall lightness or darkness of an image. However, it doesn't affect the contrast or distribution of pixel intensities.

Low-pass Filtering

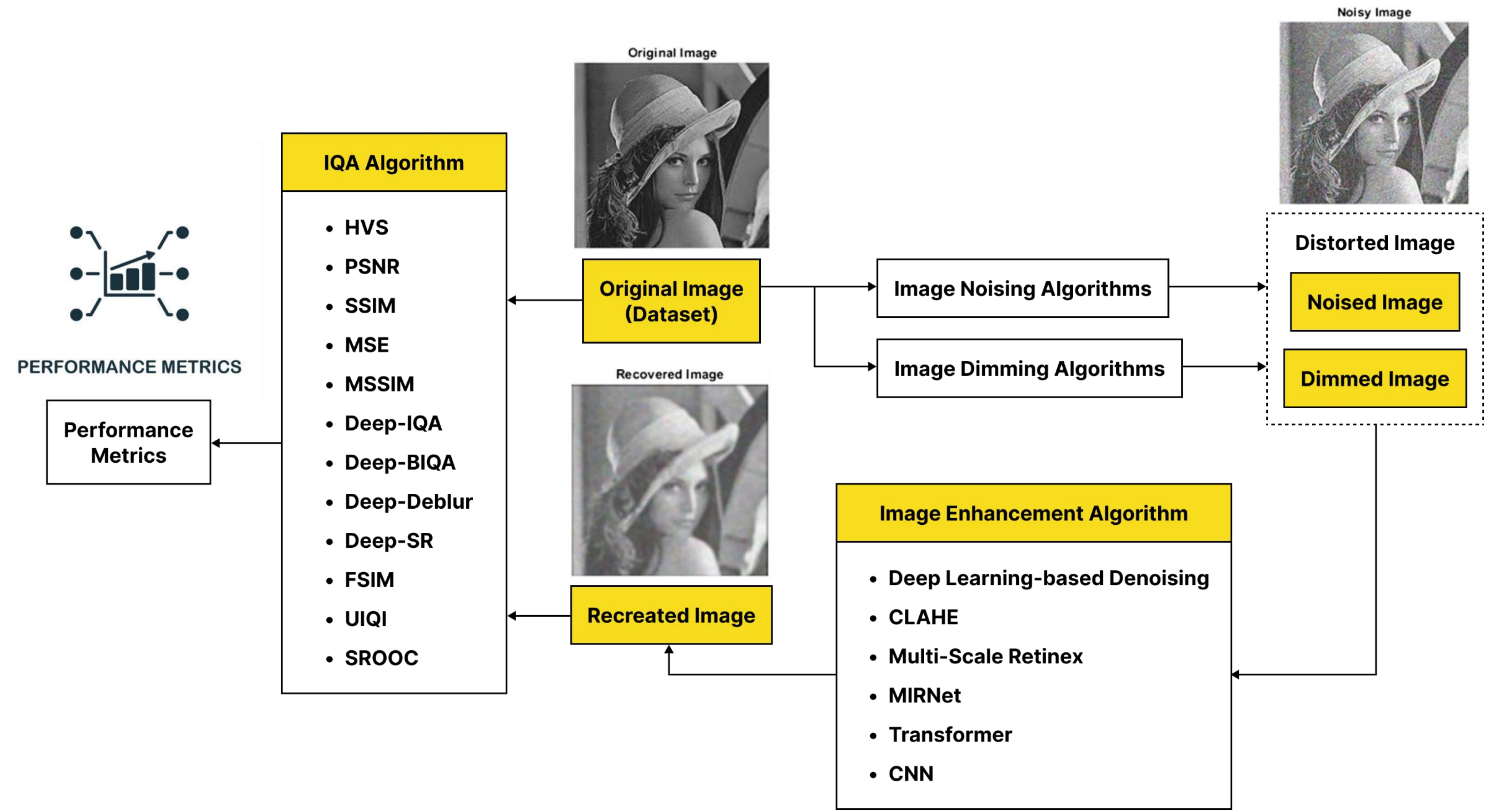
- Purpose: Low pass filtering is used to remove high-frequency noise from an image while preserving low-frequency components, such as edges and large-scale structures.
- Algorithm: Commonly used low pass filters include the Gaussian filter and the mean filter.
- Operation: These filters work by convolving the image with a kernel (a small matrix), where each pixel value in the output is calculated as a weighted average of its neighboring pixels. The weights are determined by the values in the kernel.
- Effect: Low pass filtering results in a smoother image with reduced noise. However, it may also cause blurring, especially around sharp edges and details.

Image Dimming Algorithm

Gamma Correction

- **Algorithm:** The gamma correction formula is often expressed as:
- $\mathbf{I_{out} = I_{in}}^{\gamma}$
  - Where $\mathbf{I_{out}}$ is the input intensity, $\mathbf{I_{in}}$ is the output intensity, and γ is the gamma value.
- **Operation:** When γ is less than 1, gamma correction brightens the image and enhances details in the darker regions. When γ is greater than 1, it darkens the image and enhances details in the brighter regions. A gamma value of 1 means no correction is applied.
- **Effect:** Gamma correction can be used to compensate for nonlinearities in the display device or to adjust the tonal range of an image. It's especially
- **Purpose:** Gamma correction is used to adjust the brightness and contrast of an image by nonlinearly mapping the pixel intensities.

Further into the Project



Project Doubts

- Image Quality Assessment (IQA) is done on various fields including Generic, Medical, SAR Imaging and for each field the approach can vary. So which specific field are we aiming?

- Which datasets are we working with, are we allowed to choose our own datasets for benchmarking?

- What is the preferred metric? Are we allowed to choose any metric according to us?
- What would be our **next step?**

Conclusion

In the realm of image processing, image quality assessment (IQA) techniques such as MSSIM, FSIM, and UIQI are vital for objectively measuring the fidelity and similarity of images, critical for evaluating the performance of various algorithms. Conversely, image quality enhancement (IQE) methods focus on improving image appearance, often used in tasks like denoising and super-resolution. By leveraging IQA insights to inform IQE, significant advancements in visual quality can be achieved, with implications for fields like computer vision and medical imaging. Continued research and development in both IQA and IQE are essential for furthering the capabilities and applications of image processing technologies.

Thank you