

Insight Enhancement of Distortion Effects on the Quality in Imagery Environments

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Abstract—Despite advances in technology and processing, image enhancement remains an open research area. The quality of the images has a great impact on the processing, analysis, and recognition. Images are a kind of multimedia data that demand huge resources. The image quality affects further processing, and if carefully utilized, will result in a reduction in the resources required for a specific task. Despite advancements in imagery technologies, the acquisition and transmission of digital images and other factors possess some kind of distortion. This may be attributed to transmission noise, environmental effects, and poor-quality acquiring devices and cameras, to name a few. This study compares ten image enhancement techniques for three types of imagery. The images investigated represent three classes. Micro is represented by microscopic images, Macro is represented by Macroscopic satellite images, and Photography for ordinary images. The study considers compressed images, both lossy and lossless compression, and ordinary uncompressed images. Three distortion categories, mainly Noise, Blurring, and Contrast effects, are extensively experimented with and studied. Noise types investigated are Gaussian, Poisson, Salt and Pepper, and Speckle noises. Two blurring distortions, Average Blur and Gaussian Blur, are investigated. In addition to low contrast. Distortions are applied to each image, and ten enhancement filters are applied. These include Negative, De-blur Regularized, De-blur blind deconvolution, De-blur Lucy-Richardson, Contrast Stretching, Adaptive, Gray Level Slicing, Median, Digital, and Histogram Equalization. Enhancement key performance indicators, Peak Signal to Noise Ratio, and Structural Similarity Index were measured to judge the performance of the filters. The three classes of imagery experimented with a developed tool that facilitates the experimentation and gives the KPIs for each image with a friendly User Interface. Insight is gained, thus facilitating the choice for the enhancement method.

Keywords—Digital image enhancement; distortion; image compression; filter; peak signal to noise ratio; mean square error; structural similarity index

I. INTRODUCTION

The digital image plays a major role in many applications and is used in a variety of fields. Ranging from medical applications [4], industrial production, video monitoring, intelligent transportation, remote sensing monitoring, military applications, etc. Image enhancement is a fundamental area in digital image processing that focuses on improving the visual quality and interpretability of images for human and machine vision systems. The primary objective of image enhancement is to process an image so that the enhanced image is more suitable for a specific application. The process aims to improve one or more characteristics of an image, including brightness, contrast,

sharpness, edge visibility, color fidelity, texture details, and noise reduction. [1] [2] [3][4].

Image capturing can suffer many distortions due to many factors. Poorly captured images suffer from low contrast, low brightness, blurring, noise, color, and grey-scale distortions [4]. Image enhancement methods are generally classified into two major domains, spatial and frequency domain techniques. For many years, research on image enhancement has resulted in many efforts varying from investigating a single method to comparing many. Beside study the enhancement effects on Neural networks to develop deep learning methods, [5] [6] [7] [8] [9] [10].

This study gives insights into image enhancement techniques by exploring basic enhancements on various kinds of distortions. It enables the application of distortions on images and performs, enhances, and measures the metrics for each type of distortion enhancement. The study illustrates the effect of ten enhancement techniques on distortions applied to images. It measures the enhancement on colored and gray scale for lossy, lossless compression, and ordinary images.

Images vary in their nature. The study considers three types of imagery. Micro, exemplified by medical images. Macro, exemplified by satellite imagery. And photography Ordinary camera images. In addition to noise, we include blurring and contrast effects. We developed a tool that implements the project, the Image Enhancement tool.

The study is organized as follows: Section II gives in-depth on the methodology used in this investigation. Image enhancement quality evaluation metrics are presented in Section III. Section IV detailed the experimental analysis to test the performance of the selected algorithms; Section V summarizes the findings.

II. IMAGE ENVIRONMENT

A. Image Compression

Compression is a technique that transforms an image into another. When applied does not reveal the digital image back to 100%. It can be Lossless or Lossy, where smaller compressed files are produced, number of original pixels, sound waves, or video frames is removed forever. Examples are JPEG images, MPEG videos, and audio formats.

B. Image Enhancement Categories

Image enhancement is classified into two categories, one based on the manipulation of the orthogonal transform of the

image rather than the image itself. Known as the frequency domain and is used for processing images according to the frequency content. The other category is the Spatial Domain techniques, which deal with the image pixels. The pixel values are manipulated to achieve the desired enhancement [11][12].

C. Image Enhancement Techniques

Images acquired through modern sensors may be contaminated by a variety of noise sources. Noise is stochastic variations as opposed to deterministic distortions such as shading or lack of focus. Images can suffer blurring, and be affected by contrast as well. The enhancement is a method applied to a distorted image to restore it. It works on an image by spotting hidden patterns and performing corrective actions that eliminate those distortions.

Image Enhancements considered in this study are summarized as:

- Negative: A method in which gray-level values of the pixels in an image are inverted to get its negative image. Negative images are useful for enhancing white or gray details embedded in dark regions of an image, it can be applied to a colored image by considering each color band independently.

The negative transformation in the range $[0, L-1]$ is obtained by

$$s = l - 1 - r \quad (1)$$

where, r and s are the pixel values before and after the processing on the image:

- De-blur Regularized Filter: The regulated filter uses the de-blurring method to de-blur an Image.
- De-blur blind deconvolution: The blind deconvolution algorithm performs deblurring without the PSF. The blind deconvolution algorithm can be used effectively when no information about the distortion (blurring and noise) is known.
- De-blur Lucy-Richardson: A method that performs multiple iterations, using optimization techniques and Poisson statistics.
- Contrast Stretching: Increase the dynamic range of gray levels of an image. The image can be efficiently displayed in a manner desired by the analyst.
- Gray-level Slicing: Fixed threshold values are taken for highlighting a specific range of gray values in an image. Where the desired range is made constant in intensity. There are two techniques.

Give a high value for all the gray levels in the specified range and a very low value for all the other gray levels.

Give a high value for all the gray levels in the specified range and preserve the background and gray-level tonalities in the image.

- Adaptive Filtering: noise suppression, filters a grayscale image that has been degraded by constant-power additive noise. It uses a pixelwise adaptive Wiener method based

on statistics estimated from a local neighborhood of each pixel.

- Median Filtering: a general-purpose filter that has no distinct frequency or correlation basis. In some cases, the ideal image becomes suppressed, especially when the image has low correlation from pixel to pixel.
- Digital Filtering: Computes a 2-dimensional correlation and returns the central part of the correlation with the same size as the input image.
- Histogram Equalization: A global image enhancement method that enhances image contrast. For an image with intensity levels in the range $[0, L]$, the n^{th} moment of r about its mean, m , is defined as

$$\mu_n = \sum_{i=0}^{L-1} (r_i - m)^n p(r_i) \quad (2)$$

where, m is given by:

$$m = \sum_{i=0}^{L-1} r_i p(r_i) \quad (3)$$

The mean is a measure of average intensity, and the variance (or standard deviation, σ), given by:

$$\sigma^2 = \mu_2 = \sum_{i=0}^{L-1} (r_i - m)^2 p(r_i) \quad (4)$$

is a measure of contrast. [11].

III. QUALITY METRICS

The key performance indicators used to evaluate the enhancement applied to an image are:

A. Peak Signal to Noise Ratio (PSNR)

Peak Signal to Noise Ratio (PSNR) computes Mean Square Error (MSE) reconstruction error preceding enhancement. It quantifies reconstruction quality. Higher PSNR quantifies noise removal efficiency. Additionally, it removes part of the textures. Higher PSNR indicates better image quality. It is measured in decibels (dB). Above 40 dB indicates excellent. 30-40 dB good image quality, 20-30 dB poor, and below 20 dB unacceptable, [4].

$$MSE = \frac{\sum_{i=1}^M \sum_{j=1}^N [(f(i,j) - F(i,j))]^2}{M \cdot N} \quad (5)$$

$$PSNR = 20 \cdot \log_{10} \left(\frac{255}{\sqrt{MSE}} \right) \quad (6)$$

where, $f(i,j)$ is the original signal at pixel (i,j) , $F(i,j)$ is the reconstructed signal, and $M \times N$ is the picture size.

B. Structural Similarity Index

Structural Similarity Index (SSIM) is a quality assessment, perception-based method, and is used to measure similarity between two images. Using the structural distortion measurement instead of errors. The idea considers the human vision system as highly specialized in extracting structural information from the viewing field rather than extracting errors. Thus, a measurement of structural distortion gives a better correlation to the subjective impression. It includes important perceptual phenomena, such as luminance masking and contrast. SSIM considers the similarity of the edges (high-frequency content) between an enhanced image and a reference image.

SSIM measures using an algorithm that removes the noise while preserving the edges of the objects. SSIM index is a decimal value between 0 and 1. At a high level, SSIM attempts to measure the change in Luminance, Contrast, and Structure.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y+c_1)(2\sigma_{xy}+c_2)}{(\mu_x^2+\mu_y^2+c_1)(\sigma_x^2+\sigma_y^2+c_2)} \quad (7)$$

where, μ_x and μ_y are the mean values, c_1 and c_2 are biased values, σ_x , σ_y , the variances, and σ_{xy} is the covariance.

Improved SSIM scores indicate enhanced structural fidelity and better image details. [13][14][15][16][17][18].

IV. SYSTEM DYNAMICS

The system accepts an image. Apply a selected distortion, then remove the distortion using a selected enhancement method.



Fig. 1. Requirement analysis.

Actions that Fig. 1 performs are detailed as:

- Select an Image: Upload a reference image.
- Select distortion technique: a chosen distortion is applied to the image.
- Select an enhancement method: the enhancement applies to the image, and an enhanced image is produced.
- Calculate metrics: The enhancement metrics are calculated.

V. IMPLEMENTATION AND FINDINGS

The application interface enables the user to perform the actions detailed in the previous section (Fig. 2).

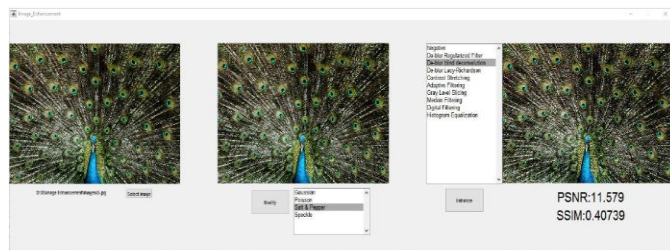


Fig. 2. System interface.

Fig. 2 shows a reference image, a distorted version of the image implementing salt and pepper noise, an enhanced image with De-blur blind deconvolution, and the metrics for this

enhancement method. The interface enables these actions by using the tabs: Upload, Modify, and Enhance, respectively.

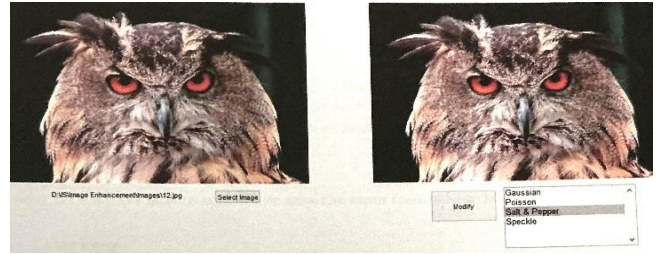


Fig. 3. Portion of the interface illustrating adding noise to a selected image.

Fig. 3 shows a portion of the user interface implementation showing the results of the select and modify tabs.

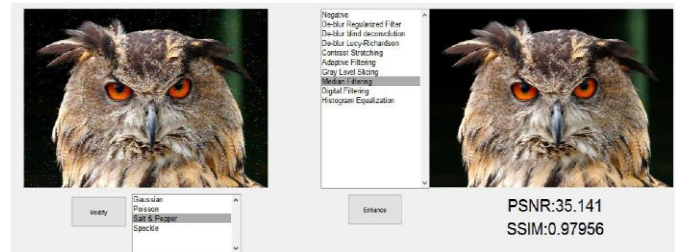


Fig. 4. Portion of the interface illustrating noise removal and metrics scores.

Fig. 4 illustrates Modify added salt and pepper noise, then enhance added Median filters on the image. The noise removal metrics PSNR and SSIM are produced and displayed as well.

As mentioned earlier, this study investigates image enhancement on micro, macro, and photography images. The implementation and results for each type of imagery are detailed in the designated table. Each table reported the results of the ten filters on the distortions and the metrics for each value. Comparisons based on SSIM and PSNR. Color indicates Dark maroon for worst results, Pastel red for bad results, Light green for good results, and dark green for best results. Neutral results are displayed with no color highlight.

A. Micro Images

The micro images studied are compressed, both lossy and lossless compressions, colored and gray-scale images. Tables I through XVIII give the results for each image. The tables give the results of applying the ten enhancement methods to seven distortions, together with the metrics for each.

Table I gives the results for a colored lossless micro image from the medical field. The colors in the table give the best to worst cases for the metrics. Dark maroon indicates the worst results, Pastel red indicates bad results, Light green indicates good results, and dark green indicates the best results. As seen in the table, the negative filter gives the worst SSIM values for micro images for three noises and two blurring distortions. The filter failed with respect to Poisson, Speckle, Salt and Pepper, Average Blur, and Gaussian Blur distortions. Digital filtering gives bad PSNR for all distortions under study. De-blur regularized filter failed to remove Gaussian, Speckle, and Salt and Pepper based on the PSNR metric. While De-blur blind deconvolution reported the same failure with Gaussian noise. Good removal filters are De-blur Richardson, Adaptive filtering,

and Median filtering. The results are highlighted in the table with the color codes given. Contrast stretching, Gray-level slicing, and Histogram Equalization give neutral results among the filters, as shown in Table I.

Table II displays the results for a lossy colored compression image. Worst results reported for the Negative filter based on SSIM. Bad results were reported on Digital filter and De-blur regularized filter for PSNR. Good results reported for Median,

De-blur blind deconvolution, De-blur Lucy Richardson on SSIM. Best results reported for the SSIM metric.

Contrast stretching and adaptive filtering produced good results for Poisson noise removal based on PSNR. Contrast stretching works fine, among others, for Gaussian blur distortion. Neutral results reported for Gray-level slicing and Histogram equalization.

TABLE I. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS COLORED MICRO IMAGE

Distortion		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	4.9491	1.4562	-68.6824	12.354	17.7948	26.9703	9.8506	26.6622	-1.3205	17.0347
	SSIM	-0.4843	0.0575	0	0.4144	0.7238	0.9459	0.2412	0.9389	0.1768	0.6843
Poisson	PSNR	4.9196	16.5047	8.4525	23.8934	21.51	31.2674	10.3586	35.5809	-1.0657	19.3752
	SSIM	-0.6078	0.6712	0.0003	0.9312	0.946	0.9802	0.2337	0.9933	0.2223	0.8642
Salt & Pepper	PSNR	4.9188	5.4829	11.4379	17.3122	21.2001	26.168	10.2477	35.3364	-1.1665	18.6727
	SSIM	-0.5654	0.1561	0.4742	0.7359	0.8972	0.9358	0.2309	0.9929	0.2048	0.8085
Speckle	PSNR	4.846	3.2599	8.4525	13.8878	20.2259	27.3245	9.8361	27.0917	-1.2062	18.0667
	SSIM	-0.5139	0.11	0.003	0.5808	0.8018	0.9506	0.2202	0.9476	0.1954	0.7347
Average Blur	PSNR	4.9896	23.6475	24.2515	30.8914	20.7568	28.1267	10.3073	30.6894	0.9549	19.0685
	SSIM	-0.5971	0.9216	0.933	0.9869	0.9386	0.964	0.2171	0.9807	0.2262	0.8501
Gaussian Blur	PSNR	4.9885	23.7288	24.2472	30.9602	20.7705	28.1815	10.309	30.7897	-0.9565	19.1013
	SSIM	-0.5974	0.9227	0.9329	0.9871	0.9392	0.9644	0.2174	0.9812	0.2262	0.8508
Low Contrast	PSNR	7.9548	14.5158	15.2813	15.2813	21.5113	15.0776	9.9921	15.2526	-3.4423	14.5505
	SSIM	-0.4785	0.5268	0.6413	0.6413	0.946	0.5995	0.2965	0.6278	0.2546	0.6597

TABLE II. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY COLORED MICRO IMAGE

Noise		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	5.0171	1.0057	16.4165	11.3822	19.6848	25.6908	9.8794	25.3711	-5.7854	11.2361
	SSIM	-0.5733	0.0764	0.6637	0.438	0.7811	0.933	0.4036	0.9289	0.1898	0.4605
Poisson	PSNR	5.0094	9.9232	21.3704	19.2899	26.5372	26.5372	10.3851	30.0697	-5.8213	11.7511
	SSIM	-0.665	0.4064	0.8762	0.8372	0.9436	0.9554	0.408	0.9746	0.2217	0.5808
Salt & Pepper	PSNR	5.0086	4.3835	19.5431	13.2572	23.2663	25.0719	10.2704	29.9614	-5.8178	11.5021
	SSIM	-0.6323	0.1671	0.8296	0.6122	0.8972	0.9235	0.3954	0.9742	0.2085	0.5504
Speckle	PSNR	5.1578	-0.2654	16.3217	10.1163	17.4302	24.1574	9.7605	22.9283	-5.5993	11.0194
	SSIM	-0.5486	0.0595	0.6534	0.3871	0.6959	0.9027	0.4048	0.8774	0.1836	0.4096
Average Blur	PSNR	5.1285	19.0445	25.8204	25.8166	23.8815	25.5188	10.2853	27.1134	-5.7658	11.5476
	SSIM	-0.6449	0.842	0.9681	0.9681	0.8964	0.9371	0.3826	0.9568	0.2243	0.5667
Gaussian Blur	PSNR	5.1268	19.1247	25.8912	25.8871	23.9416	25.5645	10.2883	27.1977	-5.7664	11.5525
	SSIM	-0.6456	0.8433	0.9685	0.9685	0.8975	0.9375	0.383	0.9575	0.2244	0.5684
Low Contrast	PSNR	8.0107	13.1463	15.428	15.4272	26.5375	15.3244	10.2873	15.5016	-3.9442	12.5864
	SSIM	-0.4675	0.3872	0.5912	0.5911	0.9436	0.5402	0.5735	0.5735	0.4521	0.4694

Table III shows the performance metrics for the uncompressed colored micro image. Again, the worst results were reported for the negative filter based on SSIM. Bad noise removal was experienced with Digital filter and De-blur regularized filters. It is interesting to see Histogram equalization and contrast stretching reported good and best results for the performance metrics. While neutral results were witnessed by five filters.

Table IV measures the effect of the seven filters on a lossless gray micro image. Negative filter produced the worst SSIM. Bad scores for Digital filter based on PSNR. De-blur regularized and De-blur blind deconvolution reported bad PSNR for Gaussian and Speckle noises, while succeeding in enhancing average blur and Gaussian blur distortions measured on both metrics.

TABLE III. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR UNCOMPRESSED COLORED MICRO IMAGE

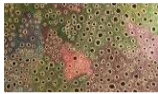
 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	4.4554	-6.7862	5.5636	4.7526	20.1503	14.0006	10.4612	12.2581	-3.602	20.0323
	SSIM	-0.781	-0.0119	0	0.1775	0.9167	0.4971	0.6389	0.3811	0.1918	0.9225
Poisson	PSNR	4.4087	-6.4383	19.5725	5.1077	28.0949	14.2984	10.8554	12.3033	-3.5396	28.4309
	SSIM	-0.8374	-0.0132	0.9409	0.2017	0.9895	0.5235	0.665	0.3925	0.2114	0.9922
Salt & Pepper	PSNR	4.4113	-6.6094	18.5888	4.9571	23.7004	14.1876	10.8177	12.2769	-3.579	22.8258
	SSIM	-0.8164	-0.0125	0.9198	0.193	0.9658	0.5142	0.6578	0.3911	0.2034	0.9611
Speckle	PSNR	4.463	-6.7646	16.6448	4.9997	20.4053	13.9923	10.3867	12.2533	-3.4075	19.5991
	SSIM	-0.7826	-0.0119	0.8763	0.1882	0.9311	0.4988	0.6262	0.3776	0.1989	0.9231
Average Blur	PSNR	6.9345	18.2812	16.0037	16.0358	11.8792	12.7379	7.454	13.2258	-3.0761	11.9663
	SSIM	-0.3001	0.876	0.7515	0.7536	0.2989	0.3573	0.2481	0.433	0.1828	0.3721
Gaussian Blur	PSNR	6.9109	18.0032	15.9387	15.962	11.9824	12.7564	7.5157	13.229	-3.0735	12.0837
	SSIM	-0.31	0.8657	0.746	0.7477	0.3142	0.3596	0.2556	0.4332	0.1863	0.3871
Low Contrast	PSNR	7.5004	0.6967	9.32	8.8825	28.0969	12.032	10.8588	11.8246	-3.5656	21.7112
	SSIM	-0.6064	-0.0318	0.2342	0.1326	0.9895	0.2319	0.6687	0.2039	0.3035	0.9444

TABLE IV. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS GRAY MICRO IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	4.8549	1.9303	17.91588	12.9609	15.419	28.0567	8.9011	27.963	-1.0477	11.8454
	SSIM	-0.0536	0.0065	0.0064	0.0577	0.1408	0.5096	0.2951	0.5221	0.0335	0.11
Poisson	PSNR	4.6465	19.3802	25.61	25.5823	15.4845	37.5108	9.4527	41.6914	-0.7876	11.4445
	SSIM	-0.0777	0.3782	0.829	0.8276	0.9174	0.9223	0.3106	0.9722	0.4472	0.4986
Salt & Pepper	PSNR	4.6436	5.7308	22.1391	17.361	16.7534	26.643	9.3759	41.362	0.8954	11.3757
	SSIM	-0.0712	0.0264	0.6107	0.4642	0.7283	0.7494	0.2455	0.9714	0.304	0.4347
Speckle	PSNR	4.5823	3.6899	13.936	14.1032	16.9281	29.4719	8.9867	28.209	0.9246	11.0111
	SSIM	-0.0534	0.0834	0.336	0.3374	0.4541	0.7851	0.2902	0.6977	0.3064	0.1144
Average Blur	PSNR	4.667	49.7755	46.7176	46.7113	15.0898	34.4843	9.4434	36.3105	0.7631	11.4173
	SSIM	0.008	0.996	0.9912	0.9912	0.9008	0.897	0.31	0.9436	0.4661	0.5086
Gaussian Blur	PSNR	4.6667	48.8402	46.5634	46.5491	15.0926	34.5389	9.4437	36.4033	0.7634	11.4177
	SSIM	0.0064	0.9945	0.9912	0.9912	0.9018	0.8975	0.31	0.9445	0.4661	0.509
Low Contrast	PSNR	7.8478	13.6972	14.0676	14.0676	15.4853	14.0562	7.4795	14.0785	4.2008	12.8503
	SSIM	0.0678	0.303	0.5954	0.5953	0.975	0.5408	0.4738	0.5953	0.202	0.5125

Table V is the result of enhancement methods on a lossy gray micro image. It shows Negative filter fails on noise removal based on SSIM. Digital filter fails based on PSNR. The best filtering is produced for the Adaptive and Median filters based on PSNR. For blurring enhancement, De-blur, blind deconvolution, and De-blur Lucy Richardson reported the best results on SSIM. Contrast stretching performs well for Poisson and Low contrast distortions. Neutral results reported for Gray-level slicing and Histogram equalization.

Table VI reports the performance of the filters on an uncompressed gray micro image. Negative filter gives the worst

results based on SSIM, except for Gaussian noise and low contrast distortions. Digital filter performs badly based on PSNR. De-blur regularized perform bad for Gaussian, Salt and Pepper, and Speckle based on PSNR. And neutral for the rest. Best and good removal of SSIM and PSNR, and reported for De-blur blind deconvolution and De-blur Lucy-Richardson, respectively, for Average blur and Gaussian blur. Contrast stretching successes for Poisson and low contrast distortions for both metrics. While PSNR reported good results for Salt and Pepper and Gaussian blur. Median filter works well for Poisson and Salt and Pepper. Complete neutral results reported for Adaptive, Gray-level slicing, and Histogram equalization.

TABLE V. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY GRAY MICRO IMAGE

Noise	Metric	Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	7.0268	1.109	-5.195	11.8465	18.8123	29.7079	8.47	27.0507	-2.9204	17.6208
	SSIM	-0.0549	0.005	0.005	0.052	0.1964	0.6817	0.0525	0.5151	0.036	0.2118
Poisson	PSNR	7.1411	15.1657	23.9526	23.9069	25.5795	35.3992	9.0109	36.1408	-2.7575	17.1944
	SSIM	-0.0668	0.1848	0.7446	0.7428	0.9889	0.8711	0.1744	0.9336	0.2684	0.8367
Salt & Pepper	PSNR	7.1189	5.7335	16.1312	15.9906	23.4816	27.1562	8.9506	36.0794	-2.8096	17.0663
	SSIM	-0.074	0.0183	0.2428	0.2371	0.6304	0.64	0.1161	0.9327	0.1335	0.5553
Speckle	PSNR	6.9833	1.692	11.9946	12.1606	20.348	27.8796	8.3836	25.9214	-2.8717	18.3991
	SSIM	-0.045	0.0094	0.1223	0.1251	0.3398	0.6806	0.0461	0.5478	0.0724	0.3256
Average Blur	PSNR	7.1849	20.3104	26.1853	26.1805	23.2468	30.9839	8.9854	32.0384	-2.712	17.0011
	SSIM	0.0663	0.5946	0.9453	0.9453	0.9127	0.8406	0.1727	0.8988	0.2989	0.8079
Gaussian Blur	PSNR	7.1844	20.4399	26.2461	26.2414	23.2984	31.0751	8.9863	32.1647	-2.7126	17.0053
	SSIM	0.0639	0.5977	0.9461	0.9461	0.9151	0.8411	0.1728	0.9001	0.2992	0.8095
Low Contrast	PSNR	10.1613	16.3593	17.5012	17.5012	25.5823	17.5161	8.8305	17.5859	-3.6811	17.0753
	SSIM	0.176	0.3448	0.7562	0.7561	0.9889	0.6746	0.217	0.7284	0.3301	0.8396

TABLE VI. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR UNCOMPRESSED GRAY MICRO IMAGE

Noise	Metric	Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	6.8233	0.3779	15.2385	10.6074	20.2009	22.9137	8.8775	23.7309	-3.4042	16.2697
	SSIM	-0.5091	0.0493	0.4263	0.3035	0.6899	0.7791	0.271	0.8212	0.152	0.6199
Poisson	PSNR	6.9625	7.629	6.2267	17.3287	34.6083	24.405	9.3896	27.1103	-3.3695	19.0742
	SSIM	-0.7032	0.2562	0.0003	0.7371	0.9931	0.8192	0.3043	0.9221	0.2216	0.9007
Salt & Pepper	PSNR	6.9432	3.9841	6.2267	14.0435	25.202	23.5371	9.3209	26.9884	-3.3067	18.3628
	SSIM	-0.6499	0.1239	0.0003	0.5772	0.9145	0.7974	0.2985	0.9207	0.2017	0.8447
Speckle	PSNR	6.8474	0.6654	15.2936	11.4166	19.991	22.9179	8.8108	23.2443	-3.327	16.6049
	SSIM	-0.524	0.0532	0.5178	0.3811	0.7278	0.7865	0.2556	0.8231	0.1644	0.6572
Average Blur	PSNR	7.4076	22.8564	28.3504	28.3464	25.0433	21.939	9.2325	24.409	-3.0852	18.0912
	SSIM	-0.6081	0.8796	0.9599	0.9599	0.9106	0.7434	0.2621	0.8627	0.2449	0.8393
Gaussian Blur	PSNR	7.4005	22.9466	28.4434	28.436	25.1845	21.9779	9.2378	24.4835	-3.0877	18.1401
	SSIM	-0.6109	0.8803	0.9608	0.9607	0.9136	0.7449	0.2631	0.8648	0.2449	0.8418
Low Contrast	PSNR	9.8724	13.5042	17.9846	17.9816	34.6088	16.7051	9.3887	17.3705	-3.3578	19.0528
	SSIM	-0.4961	0.3806	0.7359	0.7354	0.9931	0.4968	0.3066	0.6141	0.3491	0.8992

B. Photography Images

This section gives the performance of the filters on photography images. Images considered are Lossy, Lossless, and ordinary. Both compressed and uncompressed, colored, and gray scale images. Table VII summarizes Lossless colored photography image results. Negative method produced worst performance for Poisson, Salt and Pepper, Speckle, Average blur, and Gaussian blur distortions measured by SSIM. For Gaussian and low contrast, it is neutral. Digital filter reported

bad metrics for PSNR for all kinds of distortions under investigation. Contrast stretching and, Gray-level slicing and Histogram equalization are neutral for both metrics. De-blur regularized and De-blur blind deconvolution reported bad performance on PSNR for Gaussian noise removal. De-blur blind deconvolution also produced same performance for Speckle noise, while give good performance for Gaussian blur. De-blur Lucy Richardson, Adaptive filtering, and Digital filtering reported different performance that vary from best to neutral performance as seen in the table.

TABLE VII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS COLORED PHOTOGRAPHY IMAGE

Distortion		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	4.7224	1.4546	-27.8613	12.327	18.6192	26.6844	9.6147	26.2662	-2.3856	16.6169
	SSIM	-0.5771	0.1072	0.0057	0.566	0.8138	0.9623	0.4299	0.9597	0.196	0.7287
Poisson	PSNR	4.6073	12.2438	7.3174	21.7573	24.3296	31.303	10.1437	32.3851	-2.2031	18.7151
	SSIM	-0.6522	0.656	0.0003	0.9347	0.9708	0.9861	0.4424	0.9893	0.2218	0.811
Salt & Pepper	PSNR	4.608	4.933	19.5146	16.3255	23.0929	26.2515	10.0394	32.2448	-2.2674	17.9309
	SSIM	-0.6254	0.231	0.8675	0.8023	0.9417	0.9597	0.4362	0.9891	0.2116	0.7787
Speckle	PSNR	4.5292	2.0144	-0.4502	12.6783	19.4393	27.2125	9.5283	25.7252	-2.2309	16.8399
	SSIM	-0.589	0.1521	0.2931	0.6515	0.8566	0.968	0.4055	0.9614	0.2044	0.7454
Average Blur	PSNR	4.6885	23.1837	7.3174	29.9033	22.3143	27.4588	10.063	28.8997	-2.1112	18.3365
	SSIM	-0.6398	0.9453	0.0003	0.9876	0.9471	0.9701	0.4271	0.9787	0.225	0.7944
Gaussian Blur	PSNR	4.6873	23.2716	27.6908	29.9807	22.3564	27.5179	10.065	28.9779	-2.1124	18.3461
	SSIM	-0.6402	0.9461	0.9788	0.9878	0.9478	0.9704	0.4274	0.9791	0.225	0.7948
Low Contrast	PSNR	7.6265	13.471	15.1051	15.1045	24.331	14.9448	9.9517	15.093	-3.3598	14.1018
	SSIM	-0.4951	0.5045	0.627	0.6269	0.9708	0.5977	0.4497	0.6135	0.2836	0.5941

TABLE VIII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY COLORED PHOTOGRAPHY IMAGE

Distortion		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	3.9499	1.3897	-18.696	12.5505	20.0537	26.8877	11.004	26.0529	-1.9452	18.5281
	SSIM	-0.3408	0.0339	0.0494	0.2701	0.571	0.8558	0.1899	0.8222	0.1329	0.5732
Poisson	PSNR	3.8931	11.4149	9.2148	21.1978	27.3208	31.125	11.4835	31.6384	-1.7585	22.0905
	SSIM	-0.4682	0.4135	0.4717	0.8266	0.966	0.9451	0.1894	0.9646	0.2308	0.9209
Salt & Pepper	PSNR	3.8993	4.6035	-32.5947	16.3535	23.4035	25.4369	11.3163	31.5326	-1.833	20.5724
	SSIM	-0.4247	0.0852	0.7813	0.585	0.8217	0.8301	0.1788	0.9639	0.1875	0.8018
Speckle	PSNR	3.8639	2.6723	-43.5257	13.3103	22.0095	26.3354	10.9511	26.066	-1.7724	19.5725
	SSIM	-0.3687	0.0734	0.00040.8792	0.4825	0.8084	0.887	0.1788	0.897	0.1912	0.751
Average Blur	PSNR	3.9541	29.5392	24.7359	32.6535	25.2761	27.9628	11.4133	29.3122	-1.69	21.4321
	SSIM	-0.4423	0.9418	0.8792	0.9813	0.9177	0.9141	0.1679	0.944	0.2377	0.8934
Gaussian Blur	PSNR	3.9532	29.4786	24.8144	32.6717	25.3149	28.0081	11.4156	29.3777	-1.6908	21.4497
	SSIM	-0.443	0.9411	0.8816	0.9816	0.9192	0.9146	0.1683	0.9447	0.2378	0.8945
Low Contrast	PSNR	6.9767	13.0309	14.2979	14.2975	27.3233	14.2067	11.3457	14.2805	-3.2075	15.7015
	SSIM	-0.3077	0.3545	0.5228	0.5227	0.966	0.47	0.1971	0.4907	0.2586	0.6967

Table VIII displays a lossy colored image enhancement with metrics. Negative produced the same performance as with a lossless compressed image. Performance of the filters is almost the same except for De-blur regularized and De-blur blind deconvolution. Where good performance is reported for average blur and Gaussian blur enhancement on PSNR, while none is reported for De-blur blind deconvolution. Fully neutral results are obtained from Gray-level slicing and Histogram equalization.

Results for the uncompressed colored photography image are shown in Table IX. Negative method produced the worst

performance for Poisson, Salt and Pepper, Speckle for SSIM as reported for the compressed images. PSNR reported bad Gaussian removal for De-blur regularized and De-blur blind deconvolution. The latter also reported the same performance for Speckle noise removal. While performing well for blurring distortion, as did De-blur Lucy Richardson, contrast stretching works well with Poisson, as did the adaptive filter. For low contrast enhancement, contrast stretching reports good performance on PSNR. Histogram equalization shows the best and good Poisson noise removal. Digital filtering reported bad performance on PSNR for all kinds of distortions. Gray-level slicing gives neutral performance for all distortions.

TABLE IX. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR UNCOMPRESSED COLORED PHOTOGRAPHY IMAGE

Noise		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	4.6243	-0.138	-26.2324	10.6903	19.5019	23.1905	10.1794	22.247	-2.432	19.6532
	SSIM	-0.4792	0.0407	0.0053	0.3084	0.672	0.8309	0.2862	0.7936	0.1544	0.7078
Poisson	PSNR	4.5984	4.4779	17.6254	14.7542	25.0827	25.0994	10.687	23.9455	-2.2659	25.7655
	SSIM	-0.5977	0.2068	0.698	0.6749	0.9156	0.8921	0.3044	0.889	0.2231	0.9574
Salt & Pepper	PSNR	4.5998	2.1518	17.3497	13.0764	22.711	23.3416	10.5624	23.8968	-2.3287	22.7091
	SSIM	-0.5584	0.0791	0.6426	0.5293	0.8329	0.8286	0.3	0.8882	0.195	0.8649
Speckle	PSNR	4.5456	0.4763	-27.1952	11.3215	20.8075	23.3751	10.1165	22.1733	-2.3193	20.6903
	SSIM	-0.4952	0.0637	0.0875	0.4553	0.7939	0.8624	0.2703	0.8391	0.1895	0.8118
Average Blur	PSNR	4.8447	22.4843	25.4931	25.4991	20.9111	21.9051	10.277	22.8752	-2.1029	21.1764
	SSIM	-0.4971	0.8652	0.9428	0.9429	0.7634	0.8123	0.2281	0.8559	0.2319	0.8492
Gaussian Blur	PSNR	4.8418	22.4521	25.496	25.499	20.9808	21.9398	10.2876	22.9197	-2.1041	21.248
	SSIM	-0.4996	0.8639	0.943	0.9431	0.7672	0.8134	0.2295	0.8572	0.2323	0.8524
Low Contrast	PSNR	7.6169	9.7939	14.4814	14.4689	25.0838	14.6275	20.4852	14.7786	-3.2895	16.3938
	SSIM	-0.3824	0.1999	0.4751	0.4731	0.9156	0.3889	0.2958	0.4202	0.278	0.7285

TABLE X. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS GRAY PHOTOGRAPHY IMAGE

Noise		Enhancement Method									
		Metric	Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering
Gaussian	PSNR	4.4101	1.5375	6.5716	12.6943	20.7327	29.351	11.1363	27.272	-2.9921	14.3087
	SSIM	-0.0433	0.0053	0.0142	0.0585	0.2171	0.7079	0.1809	0.5282	0.0347	0.1816
Poisson	PSNR	4.0705	15.842	25.761	25.7273	37.4614	35.2438	11.618	36.294	-2.9562	15.6659
	SSIM	-0.066	0.3357	0.7975	0.7957	0.9873	0.8764	0.1985	0.9267	0.2973	0.8019
Salt & Pepper	PSNR	4.0758	5.1572	16.3423	16.15	24.4369	25.8036	11.4425	36.1679	-3.0009	15.2044
	SSIM	-0.0625	0.0206	0.4074	0.3928	0.7552	0.6907	0.1535	0.926	0.1978	0.6278
Speckle	PSNR	4.1571	3.0154	6.5716	13.364	21.7514	26.3883	11.2379	26.688	-2.6785	15.0145
	SSIM	-0.0461	0.0203	0.0142	0.193	0.4464	0.6654	0.1758	0.6267	0.1003	0.3365
Average Blur	PSNR	4.0927	22.8789	29.6961	29.6925	32.4192	31.9555	11.5992	13.0391	-2.9284	15.6208
	SSIM	0.0393	0.7712	0.9523	0.9523	0.8003	0.8365	0.1959	0.8902	0.3212	0.7708
Gaussian Blur	PSNR	4.0924	22.9726	29.7687	29.7652	32.529	32.0133	11.5998	33.1281	-2.9288	15.6229
	SSIM	0.0371	0.771	0.9529	0.9520	0.9019	0.8367	0.1959	0.8914	0.3219	0.7731
Low Contrast	PSNR	7.0918	14.1865	14.6811	14.681	37.4655	14.6572	11.6152	14.6898	-3.1808	15.6412
	SSIM	0.1841	0.439	0.6998	0.6997	0.9873	0.6169	0.2005	0.6628	0.3142	0.8106

In Table X, a lossless gray photography image is tested for insight enhancement performance on the distortions specified. Negative produced the worst SSIM for noise removal. Neutral results for blurring and contrast enhancements. De-blur regularized reported the worst and bad performance for Gaussian noise removal and bad speckle removal. The Digital filter again performs badly based on PSNR. Best results reported for Average blur and Gaussian blur based on PSNR for De-blur blind deconvolution and De-blur Lucy Richardson. Contrast stretching performs well for Poisson removal, blurring, and contrast enhancements. Adaptive filtering for Poisson and Gaussian blurring showed good performance. The median filter also performed well for Poisson, Salt and Pepper, average blur,

and Gaussian blur in terms of PSNR. Gray-level slicing and Histogram equalization reported neutral for all distortions.

Table XI reported results for a lossy gray photography image. Negative produced the worst SSIM except for blurring removal. Neutral results reported for Adaptive, Gray-level slicing, and Histogram equalization. Digital filtering reported similar PSNR for distortions. Best and good results scattered for De-blur regularized in blur enhancement for both Average and Gaussian, De-blur Lucy Richardson for blurring enhancement as well, contrast stretching for Gaussian, Poisson, and Salt and Pepper removals, besides low contrast enhancement. Median for Poisson and Salt and Pepper.

TABLE XI. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY GRAY ORDINARY IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	1.7548	-1.7425	3.308	7.4912	21.6734	18.4125	14.7443	19.4072	-7.1631	12.5738
	SSIM	-0.3663	0.0698	0.161	0.3042	0.7246	0.6305	0.6739	0.7087	0.1585	0.5498
Poisson	PSNR	1.515	-0.4764	2.0226	9.5962	12.27244	19.4357	15.1881	20.3165	-7.4613	12.6121
	SSIM	-0.3831	0.1025	0.0227	0.4782	1	0.6925	0.6777	0.8321	0.2499	0.6235
Salt & Pepper	PSNR	1.5323	-1.5589	2.1303	9.1207	23.6812	18.9153	14.6518	20.1639	-7.4378	12.2297
	SSIM	-0.3709	0.0781	0.213	0.4311	0.8528	0.6548	0.581	0.8293	0.1905	0.5715
Speckle	PSNR	1.9646	-2.5548	-203.6452	8.5801	18.3589	17.25	14.6131	18.1461	-6.7364	12.2699
	SSIM	-0.3671	0.0623	0.0882	0.3779	0.6718	0.603	0.6745	0.6277	0.1706	0.5187
Average Blur	PSNR	2.027	25.1248	14.4358	22.5358	18.1736	15.9339	13.3406	17.1045	-7.2574	11.2853
	SSIM	-0.2773	0.9431	0.5199	0.9077	0.7586	0.5428	0.5169	0.6898	0.2834	0.5321
Gaussian Blur	PSNR	2.0198	24.7907	13.9909	22.5362	18.3018	15.9774	13.3988	17.1715	-7.259	11.3043
	SSIM	-0.2807	0.9315	0.5171	0.9082	0.7661	0.5453	0.5209	0.6938	0.2846	0.5373
Low Contrast	PSNR	4.613	6.4466	11.6897	11.6599	24.6906	11.2021	15.1881	11.6943	-4.283	11.9894
	SSIM	-0.3069	0.1964	0.6062	0.6017	1	0.4093	0.6777	0.5138	0.4373	0.6908

TABLE XII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR AN UNCOMPRESSED GRAY ORDINARY IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	3.5858	-0.8225	8.0105	10.6085	20.8104	21.7001	11.132	21.0616	-1.6251	12.3396
	SSIM	-0.3686	0.0308	0.0553	0.2512	0.6273	0.574	0.2638	0.6112	0.127	0.4773
Poisson	PSNR	3.4763	2.1035	16.4471	13.3667	32.9088	22.9341	11.6328	22.3551	-1.4307	13.162
	SSIM	-0.4784	0.0726	0.4754	0.5259	0.9971	0.6733	0.2687	0.7522	0.2406	0.6513
Salt & Pepper	PSNR	3.4839	0.4871	-25.99815	12.2545	24.2201	21.8025	11.4502	22.3003	-1.5108	12.9193
	SSIM	-0.4467	0.047	0.0412	0.4505	0.8915	0.618	0.2525	0.7505	0.2047	0.5988
Speckle	PSNR	3.4501	-0.2055	7.4218	11.2676	22.4115	22.0827	11.0975	21.1847	-1.4634	12.8447
	SSIM	-0.3878	0.0423	0.2674	0.4324	0.8568	0.6655	0.2518	0.7021	0.205	0.5548
Average Blur	PSNR	3.7517	25.1915	24.9368	24.9475	20.5853	20.3003	11.0766	21.2661	-1.1765	12.639
	SSIM	-0.2897	0.8465	0.89	0.8904	0.7398	0.5539	0.1754	0.6748	0.2648	0.5081
Gaussian Blur	PSNR	3.7484	25.0361	24.9733	24.975	20.6828	20.3288	11.0893	21.3113	-1.1782	12.658
	SSIM	-0.2944	0.842	0.8915	0.8918	0.7475	0.5555	0.1768	0.6781	0.2661	0.5134
Low Contrast	PSNR	6.5629	8.3607	13.5009	13.4769	32.9143	13.4127	11.5911	13.5538	-3.0227	13.1525
	SSIM	-0.3521		0.4551	0.4498	0.9971	0.2757	0.2829	0.3326	0.2315	0.6535

Table XII displays an uncompressed gray ordinary image result. Negative performs worst except for blurring. Digital reported bad results for distortions. Neutral results reported for Gray-level, Median, and Histogram equalization. For blurring enhancement, the performance of De-blur regularized, De-blur blind deconvolution, and De-blur Lucy Richardson was reported to be good on PSNR and best on SSIM for the last two. Contrast stretching performs well for Poisson and Salt and Pepper noise removal, in addition to low contrast enhancement.

C. Macro Images

Section C reported results of the 10 filters on lossless, lossy,

and uncompressed colored satellite images. The compressed and uncompressed gray satellite images are considered as well.

Table XIII reported lossless colored macro image enhancement results. Best blurring enhancement achieved by De-blur regularized, De-blur blind deconvolution, and De-blur Lucy Richardson. Median produced a good Gaussian blurring enhancement. Contrast enhancement best results are reported for contrast stretching. Digital filtering performs badly based on PSNR. Negative reported the worst results for Poisson, Salt and Pepper, Average blur, Gaussian blur, and low contrast.

TABLE XIII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS COLORED MACRO IMAGE


		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	8.5245	0.2456	7.1741	10.6863	17.2548	23.8054	8.1926	23.7806	-2.5233	15.9065
	SSIM	-0.4261	0.0259	0.0002	0.2061	0.5299	0.6831	0.1771	0.6989	0.1204	0.4975
Poisson	PSNR	8.8066	7.6821	17.6305	17.4386	21.5765	25.5937	8.7588	26.6837	-2.3311	16.4511
	SSIM	-0.6692	0.1266	0.5908	0.5791	0.9398	0.7532	0.2032	0.849	0.2231	0.7586
Salt & Pepper	PSNR	8.756	4.1033	14.5551	14.3149	21.2891	24.1781	8.7114	26.6162	-2.3961	16.3787
	SSIM	-0.5866	0.0613	0.4101	0.3944	0.8328	0.7026	0.1996	0.8475	0.1824	0.6928
Speckle	PSNR	8.5717	1.1222	7.1741	11.8711	19.308	23.956	8.2252	23.6582	-2.4725	16.6152
	SSIM	-0.4619	0.0319	0.0002	0.2714	0.6004	0.6959	0.1649	0.7032	0.1368	0.5424
Average Blur	PSNR	9.2598	25.8571	29.3332	29.3331	19.9576	23.3933	8.5885	25.0953	-2.2047	15.7452
	SSIM	-0.4862	0.9019	0.9365	0.9365	0.8386	0.6587	0.1528	0.7843	0.2522	0.6999
Gaussian Blur	PSNR	9.2536	25.8838	29.3725	29.37	19.9952	23.424	8.5939	25.1502	-2.205	15.7611
	SSIM	-0.4906	0.9005	0.9371	0.9371	0.8429	0.6602	0.1539	0.7868	0.2525	0.7036
Low Contrast	PSNR	11.5668	12.0807	18.3731	18.3591	21.5779	18.3349	8.4636	18.7731	-3.8061	15.5871
	SSIM	-0.5134		0.675	0.6731	0.9398	0.5401	0.2479	0.6473	0.2892	0.7387

TABLE XIV. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY COLORED MACRO IMAGE


		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	9.4141	0.7991	11.3507	11.4129	16.9719	27.7898	8.1516	26.3343	-2.3683	14.7554
	SSIM	-0.2513	0.0119	0.1089	0.1097	0.2797	0.7823	0.0868	0.6974	0.0811	0.2802
Poisson	PSNR	9.8063	13.7843	23.9378	23.8913	17.3057	31.9443	8.6961	32.9808	-2.1631	14.8163
	SSIM	-0.5489	0.2333	0.7597	0.758	0.6896	0.8943	0.1108	0.9358	0.2273	0.6374
Salt & Pepper	PSNR	9.7356	5.853	16.2159	16.1125	16.8585	26.7697	8.6509	32.9067	-2.2331	14.8035
	SSIM	-0.4394	0.0399	0.3394	0.3331	0.5708	0.7478	0.1065	0.9349	0.1665	0.5364
Speckle	PSNR	9.519	2.0696	12.5451	12.7044	16.2623	27.3054	8.2375	26.0518	-2.3068	15.3003
	SSIM	-0.2897	0.0157	0.148	0.152	0.3296	0.8015	0.0782	0.7189	0.1049	0.3155
Average Blur	PSNR	9.9547	26.508	33.0022	33.0003	17.4427	29.1415	8.6358	30.7264	-2.1159	14.6159
	SSIM	-0.4497	0.8831	0.9643	0.9643	0.6829	0.8405	0.092	0.8983	0.2427	0.6454
Gaussian Blur	PSNR	9.9527	26.6172	33.1031	33.1007	17.4496	29.1857	8.6376	30.7949	-2.1165	14.6194
	SSIM	-0.452	0.8836	0.9647	0.9647	0.6846	0.8415	0.0924	0.8997	0.2428	0.6465
Low Contrast	PSNR	11.116	15.9929	23.68	23.6689	17.305	24.7439	8.6653	25.2476	-2.5862	14.2612
	SSIM	-0.3071	0.2351	0.6714	0.6707	0.6895	0.6467	0.108	0.7101	0.2675	0.5831

Table XIV reported lossy colored macro image results. Best luring enhancement reported for De-blur blind deconvolution, and De-blur Lucy Richardson. Adaptive and Median filtering also reported good performance on PSNR. Noise removal achieved the best SSIM for Median on Poisson noise, while PSNR reported good results for passion, Salt and Pepper, Average blur, and Gaussian blur. Digital filter reported weak PSNR for all distortions. De-regularized reports similar performance for Gaussian, Salt and Pepper, and Speckle noise removal.

Uncompressed colored macro image results are shown in Table XV. Negative filter performance was reported as worst on Poisson, Salt and Pepper, Average, Gaussian blur, and Low contrast. The Digital filter also performs badly except for the Average blur. For blurring enhancement, De-blur Richardson reported good and best performance on PSNR and SSIM, respectively. Contrast stretching achieved the best noise removal based on SSIM for Poisson noise, and the best SSIM for low contrast enhancement. Adaptive filter performs well for Gaussian, Poisson, Salt and Pepper, and Speckle based on PSNR.

TABLE XV. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR UNCOMPRESSED COLORED MACRO IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	6.9584	0.3041	21.3381	11.1216	17.7685	25.7688	8.5676	23.9856	-2.6037	16.9936
	SSIM	-0.3629	0.0176	0.0112	0.1606	0.4456	0.6968	0.2177	0.6661	0.1026	0.4652
Poisson	PSNR	6.9929	6.8399	22.1874	17.4137	18.6496	28.4654	9.1077	26.4352	-2.4183	18.2794
	SSIM	-0.6218	0.1257	0.808	0.6284	0.9399	0.8286	0.243	0.8536	0.2571	0.7915
Salt & Pepper	PSNR	6.9712	3.556	-28.7838	14.3469	19.3795	25.2719	9.045	26.4031	-2.4793	17.8612
	SSIM	-0.5322	0.0431	0.015	0.3917	0.7919	0.7133	0.2	0.8525	0.1818	0.6852
Speckle	PSNR	6.8372	0.9052	-3.1781	11.7186	19.6912	25.6903	8.568	23.6576	-2.5583	17.6717
	SSIM	-0.3916	0.0264	0.4299	0.2879	0.5921	0.7646	0.2058	0.7154	0.1709	0.5045
Average Blur	PSNR	7.1862	24.7441	-14.959	27.5731	16.6835	25.1337	8.9266	25.8319	-2.3567	17.2665
	SSIM	-0.4473	0.8332	0.7975	0.9289	0.7994	0.7523	0.1992	0.8119	0.27	0.7201
Gaussian Blur	PSNR	7.184	24.6481	7.0942	27.577	16.7035	25.1795	8.9328	25.875	-2.357	17.2876
	SSIM	-0.4513	0.8302	0.0774	0.9295	0.8041	0.7534	0.2001	0.8136	0.2706	0.7245
Low Contrast	PSNR	10.04	11.589	16.1181	16.1134	18.6509	16.5368	8.3562	16.5271	-4.1663	16.3612
	SSIM	-0.4234	0.1702	0.5567	0.5554	0.9399	0.4987	0.2847	0.5445	0.2769	0.7097

TABLE XVI. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSY GRAY MACRO IMAGE

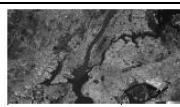
 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	6.2452	-3.3558	12.7743	8.8843	19.3859	19.2621	9.3728	18.1566	-1.6874	13.0794
	SSIM	-0.5512	0.0282	0.4866	0.2578	0.6997	0.4472	0.2897	0.4358	0.1431	0.5685
Poisson	PSNR	6.3657	-1.6396	14.8625	11.0544	30.6998	20.1136	9.8726	18.7738	-1.4563	14.3647
	SSIM	-0.6917	0.0419	0.5727	0.4201	0.9881	0.4964	0.3087	0.5187	0.2212	0.8139
Salt & Pepper	PSNR	6.3512	-2.2411	13.9067	10.4148	24.9784	19.6691	9.7866	18.7393	-1.5477	14.1549
	SSIM	-0.6517	0.0364	0.2897	0.3669	0.9192	0.4724	0.3058	0.5171	0.1969	0.7738
Speckle	PSNR	6.2812	-2.781	12.3243	9.8708	21.3404	19.5612	9.4096	18.2706	0.1706	13.599
	SSIM	-0.5868	0.032	0.52	0.3247	0.8143	0.4814	0.2779	0.4737	0.1706	0.6596
Average Blur	PSNR	7.3757	22.4106	21.4357	21.4453	15.3818	17.7486	8.8322	18.2377	-1.1086	12.4574
	SSIM	-0.2459	0.8332	0.7747	0.7757	0.5669	0.3111	0.1098	0.42	0.2432	0.5348
Gaussian Blur	PSNR	7.365	22.2428	21.4991	21.5013	15.487	17.7735	8.863	18.2658	-1.1089	12.5124
	SSIM	-0.2562	0.827	0.7794	0.7802	0.5816	0.3134	0.114	0.4239	0.2471	0.5485
Low Contrast	PSNR	9.2984	5.0334	15.2332	14.9748	30.7015	15.4942	9.8266	15.4786	-3.1398	14.3443
	SSIM	-0.5106	0.0839	0.5753	0.5425	0.9881	0.2809	0.3291	0.3116	0.2774	0.8129

Table XVI shows results for the lossy gray macro image. Negative method produced the worst performance for Gaussian, Poisson, Salt and Pepper, Speckle, and low contrast based on SSIM. The Digital filter also performs badly except for the Average blur. De-blur regularized works well for blurring enhancement. Contrast stretching performs well for Poisson, Salt and Pepper, Speckle, and Low contrast enhancements. Neutral results are obtained for all distortions reported for Adaptive, Median, Gray-level Slicing, and Histogram equalization.

Table XVII reported enhancement results for a lossless gray macro image. Negative filter reported the worst SSIM for noise

removal on all noise types, in addition to Gaussian blur enhancement. Performance of the Digital filter PSNR reported bad performance against others. Besides De-blur regularized performance for Gaussian and Speckle noise removal, and De-blur blind deconvolution for Salt and Pepper noise removal. For blurring enhancement, De-blur Lucy Richardson reported the best and good SSIM and PSNR, respectively. Contrast stretching performs well for Poisson noise and Low contrast enhancements. Adaptive filtering did well for all noise kinds. Median filtering competes for Poisson and Salt and Pepper noise removal.

TABLE XVII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR LOSSLESS GRAY MACRO IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	3.2583	0.3299	9.5034	12.0956	20.2881	24.1073	11.8037	22.8442	0.235	10.3059
	SSIM	-0.2632	0.0285	0.1753	0.2048	0.4577	0.5948	0.3464	0.6007	0.0958	0.3097
Poisson	PSNR	3.1287	4.8491	9.5034	18.3003	29.7177	26.9783	12.2716	24.493	0.0518	10.7031
	SSIM	-0.3652	0.0886	0.1753	0.7574	0.9928	0.8161	0.353	0.865	0.3628	0.5255
Salt & Pepper	PSNR	3.138	2.1709	26.582	15.6214	23.9044	24.4145	12.0556	24.4456	0.0764	10.6011
	SSIM	-0.3361	0.0508	0.1747	0.5692	0.8502	0.7254	0.3041	0.8637	0.2716	0.4773
Speckle	PSNR	3.1064	1.9612	12.4028	14.6432	23.8268	25.0197	11.7976	23.2871	0.0034	10.557
	SSIM	-0.286	0.0423	0.3601	0.5405	0.8206	0.7907	0.3365	0.7966	0.3088	0.4047
Average Blur	PSNR	3.2936	23.6974	9.5034	28.957	22.1945	22.5311	11.8549	23.4673	0.3628	110.5401
	SSIM	-0.2565	0.7706	0.1753	0.9511	0.8583	0.7085	0.2783	0.8098	0.3843	0.448
Gaussian Blur	PSNR	3.2914	23.3367	23.0032	29.1982	22.2817	22.5839	11.8641	23.5119	0.3598	10.547
	SSIM	-0.2595	0.76	0.8007	0.9554	0.8629	0.7103	0.2791	0.8121	0.3848	0.4508
Low Contrast	PSNR	6.447	9.8478	13.3459	13.3381	29.7213	13.2368	12.136	13.3517	2.8746	11.0058
	SSIM	-0.2422	0.1458	0.4862	0.4842	0.9928	0.3494	0.3765	0.3952	0.204	0.5282

TABLE XVIII. PERFORMANCE OF ENHANCEMENT METHODS ON DISTORTION TYPES FOR UNCOMPRESSED GRAY MACRO IMAGE


 Noise Metric		Enhancement Method									
		Negative	De-blur Regularized Filter	De-blur blind deconvolution	De-blur Lucy-Richardson	Contrast Stretching	Adaptive Filtering	Gray Level Slicing	Median Filtering	Digital Filtering	Histogram Equalization
Gaussian	PSNR	4.7725	-0.6596	12.8548	9.3736	20.4373	18.6575	10.5562	20.5453	-4.2811	19.327
	SSIM	-0.5875	0.0901	0.4122	0.4301	0.8115	0.6591	0.4814	0.8045	0.1792	0.793
Poisson	PSNR	4.7934	3.2133	16.3253	12.8013	12.33671	19.3428	11.0309	21.9149	-4.2384	25.5406
	SSIM	-0.684	0.202	0.7562	0.6638	1	0.6926	0.5062	0.8665	0.2219	0.9652
Salt & Pepper	PSNR	4.7928	1.3128	-29.6138	11.3039	24.714	18.9848	10.8913	21.8395	-4.2612	22.1598
	SSIM	-0.6535	0.1421	0.6136	0.5819	0.9421	0.6761	0.4951	0.8647	0.2085	0.9152
Speckle	PSNR	4.8409	-0.698	12.4154	9.9906	20.149	18.5017	10.498	19.9541	-4.1042	19.5778
	SSIM	-0.5972	0.0883	0.4919	0.4956	0.839	0.6594	0.4676	0.7935	0.1921	0.8199
Average Blur	PSNR	5.493	30.0563	27.3753	27.3827	21.316	17.4243	10.5677	19.5291	-3.9327	20.1496
	SSIM	-0.5669	0.9748	0.9661	0.9662	0.8557	0.5747	0.4266	0.7601	0.2611	0.8467
Gaussian Blur	PSNR	5.4819	29.5567	27.4728	27.4607	21.4674	17.4512	10.5893	19.5875	-3.936	20.2649
	SSIM	-0.5709	0.9715	0.9672	0.9671	0.861	0.5766	0.429	0.7634	0.2611	0.8515
Low Contrast	PSNR	7.8914	10.2821	15.606	15.5919	24.4513	13.8039	11.0309	14.5404	-3.4682	25.4996
	SSIM	-0.5056	0.3443	0.7261	0.7249	1	0.3535	0.5062	0.4987	0.3626	0.9645

Table XVIII displays enhancement methods on an uncompressed gray macro image. Negative filter reported the worst SSIM for noise removal on all noise types, in addition to Gaussian blur enhancement. The performance of the Digital filter PSNR was reported as bad. Best blurring enhancement reported for De-blur regularized, De-blur blind deconvolution. For contrast enhancement, contrast stretching and histogram equalization perform superior on others.

The tables for the three categories are further visualized in bar graphs that demonstrate the effects of the 10 filters on the 7 distortions.

Fig. 5 visualizes the PSNR that measures the effectiveness of the filters on the distortions over the micro images. The category includes Lossy, Lossless, both colored and uncolored, and compressed and uncompressed. The filters shown in the legend are indicated by the colors that distinguish each.

The PSNR measures the effectiveness of the filters on the distortions over the ordinary images (Fig. 6). The category includes the Lossy, Lossless, both colored and uncolored, and compressed and uncompressed. The filters shown in the legend are indicated by the colors that distinguish each.

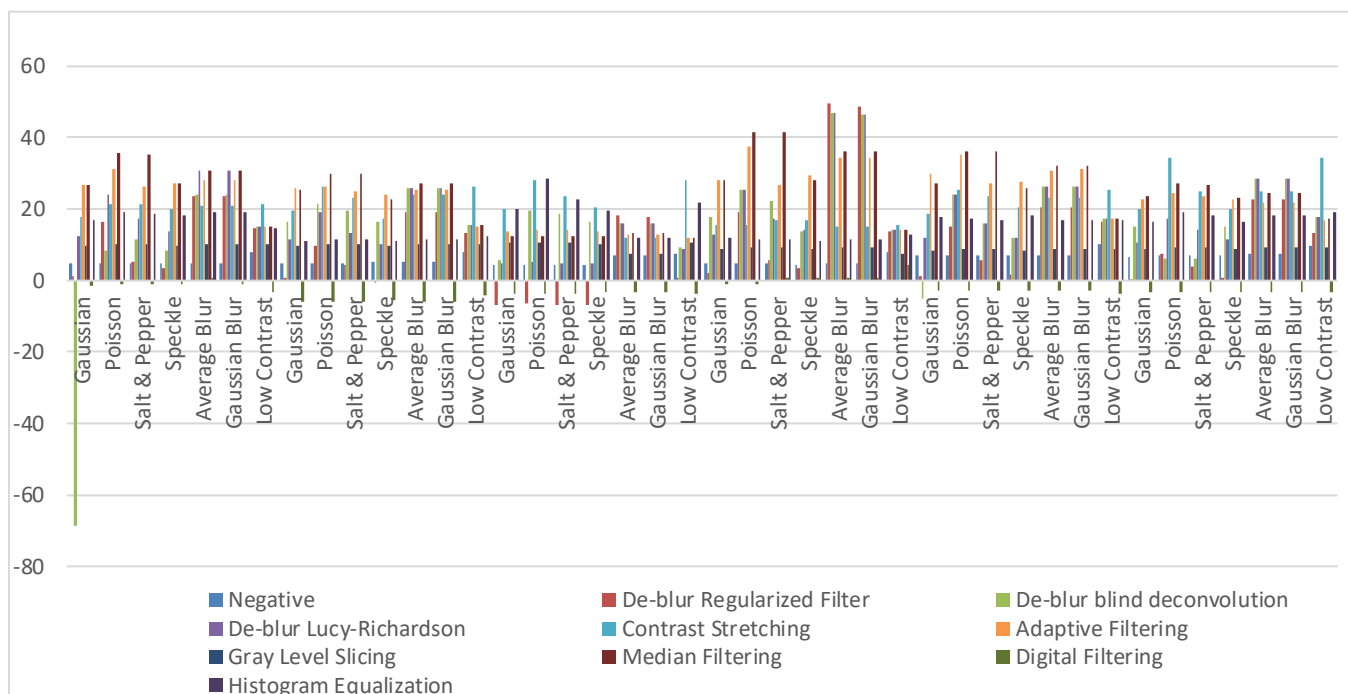


Fig. 5. Performance of enhancement filters on the distortion for micro images.

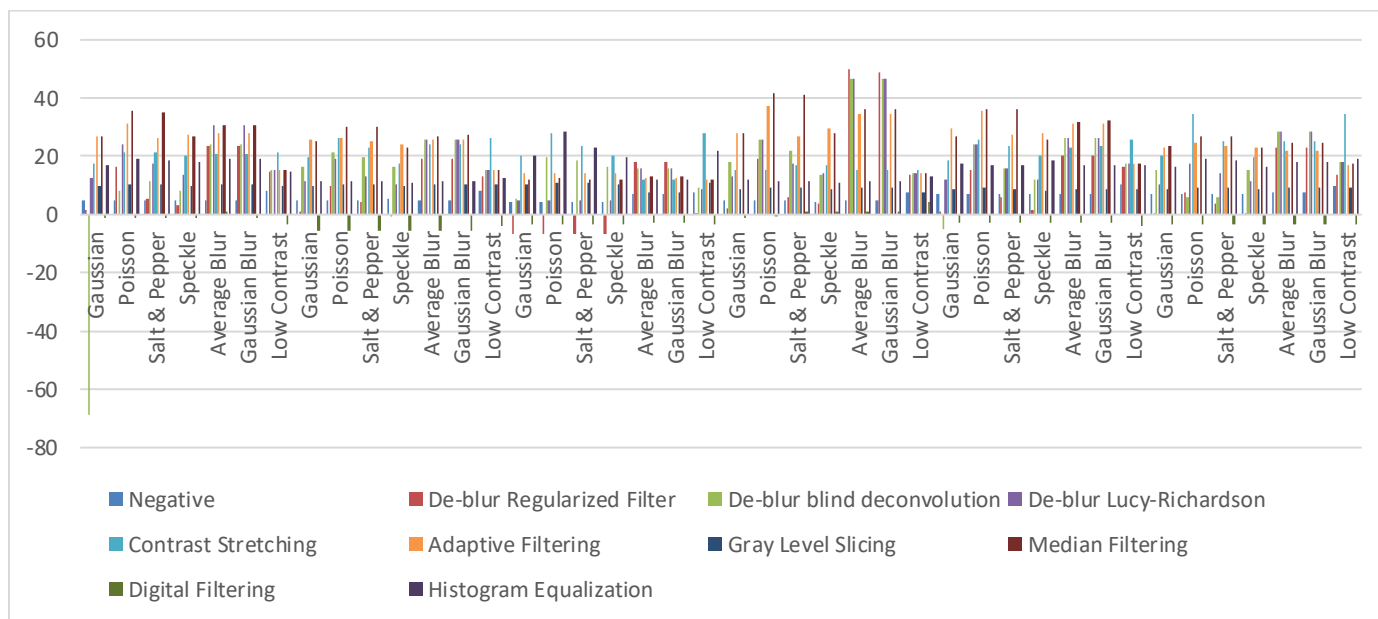


Fig. 6. Performance of enhancement filters on the distortion for ordinary images.

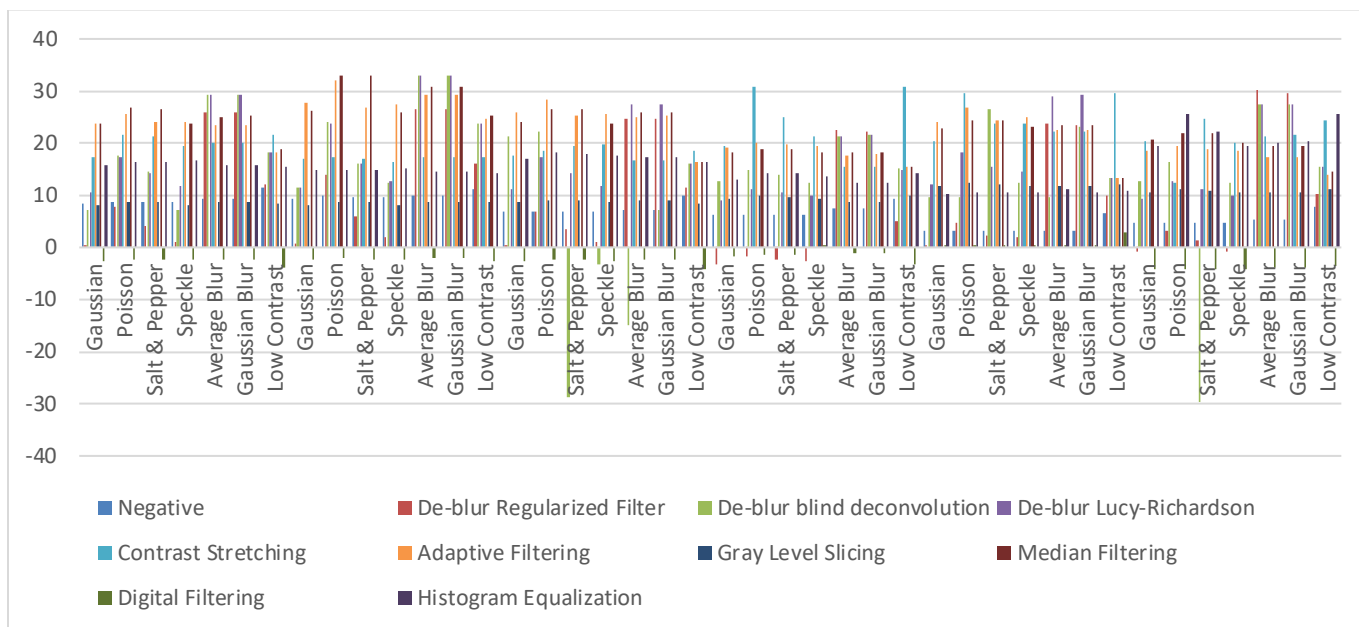


Fig. 7. Performance of enhancement filters on the distortion for macro images.

Fig. 7 visualizes the PSNR that measures the effectiveness of the filters on the distortions over the macro images. The category includes Lossy, Lossless, both colored and uncolored, and compressed and uncompressed. The filters shown in the legend are indicated by the colors that distinguish each.

VI. CONCLUSIONS AND RECOMMENDATIONS

In this study, an investigation and comparison of Negative, De-blur Regularized, De-blur blind deconvolution, De-blur Lucy-Richardson, Contrast Stretching, Adaptive, Gray Level Slicing, Median, Digital, and Histogram Equalization filters on distortions are applied to micro, macro, and photography images. Key performance indicators that judge the performance are Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM). Section V gives the findings and results for the 10 enhancement methods. Negative filter fails to enhance the micro, photography, and macro images based on the SSIM metric, while producing neutral results for PSNR. De-blur Regularized filter sometimes reported good performance for blurring enhancement, but overall, across the three categories, it fluctuates and tends towards the worst category (Table XIX). Digital filtering reported bad PSNR for all three categories. De-blur blind deconvolution failed to compete for higher achievement with other filters. Besides gray-level slicing and Histogram equalization, these methods may be more effective in specific applications. The best methods reported for all three categories, whether compressed or uncompressed, colored, or gray, are reflected in Table XIX. It is found that De-blur, Richardson, Median, and Contrast stretching are the best among others. To strengthen the performance, hybrid filtering may introduce more enhancement capabilities.

De-blur Lucy-Richardson, Contrast Stretching, and Media Filtering have the best performance over all image types. Negative and Digital filtering have the worst performance over all image types. Histogram Equalization and Grey Level Slicing always give a moderate performance in all image types, but it

has a good result if the image is not compressed. De-blur Regularized Filter and De-blur blind deconvolution have good performance when the image suffers from Blur distortion. Contrast Stretching has good performance when the image suffers from low contrast.

TABLE XIX. RECOMMENDED ENHANCEMENT METHODS FOR MICRO VERSUS MACRO AND ORDINARY IMAGES

Image Type	Best Enhancement Method	Worst Enhancement Method
Mico (Medical)	De-blur Lucy-Richardson	Negative
	Median Filtering	Digital Filtering
	Contrast Stretching	De-blur Regularized Filter
Ordinary Photography	De-blur Lucy-Richardson	Negative
	Contrast Stretching	Digital Filtering
	Median Filtering	De-blur Regularized Filter
Macro (Satellite)	De-blur Lucy-Richardson	Negative
	Contrast Stretching	Digital Filtering
	Median Filtering	De-blur Regularized Filter

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