ANALYSIS OF IMAGE ENHANCEMENT ON MEDICAL ENDOSCOPIC IMAGE*

Aung Thiha[1], Myat Su Hlaing[2], Soe Mya Mya Aye[3]

Abstract

In clinical surgery, the quality of endoscopic image is degraded by noise. Bloods, illumination changes, specular reflection and other factors contributes to noise affect doctor's judgement, and cause high operation risk. In this research, degraded image is restored by using linear and non-linear methods to make better enhancement. For noise removal, arithmetic mean, harmonic mean, contraharmonic mean and median filters are used. Unsharp masking_filter is used to make sharping image. Gamma correction method is used for color enhancement and tone-mapping. The simulation programs are written using MATLAB. Both linear and non-linear filters are analyzed for specific image processing. The results of these two classes of filter are compared by Image Quality Assessment (IQA). This research assists the physicians to determine the diseases by applying linear and non-linear filter over the endoscopic image that have degraded factors.

Keywords: Endoscopic image, degraded image, image restoration, IQA

Introduction

Image processing begins with the capture of an analog image by suitable devices, which is then converted to digital image before the image is processed by computer for better visual appearance to a human viewer. Most image have noise which creates blur and degrade the quality of image. Filtering is a technique for modifying or enhancing an image. Spatial domain operation or filtering is the processed value for the current pixel depends on both itself and surrounding pixels. Hence Filtering is a neighborhood operation, in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel.

In fiber-optic endoscopes, various optical viewing bundles are used to transmit images. Images transmitted to the top of the bundles by each optical fiber yield an image through a focusing lens, with the resulting image viewed through an eyepiece. Optical fibers are prone to damage and damaged optical fiber bundles affect the clarity of the image. To overcome this problem, video-endoscopy was developed in 1990s, using charge-coupled devices (CCDs). CCDs consist of an array of individual photocells, called picture elements or pixels, that receive photons reflected back from the mucosal surface and produce electrons in proportion to the light reflected on the CCDs. The variable charge thus generated is electronically transmitted to a video processor and converted into a digital image. The resolution of images depends on the number of pixels in the array, with higher the pixel density providing a higher resolution for detailed images of a lesion. (Fang et al., 2021)

Endoscopic image is a very wide class of medical images obtained by examining various organs and body cavities by via the special optoelectronic device endoscope. The types of endoscopies are: gastroscopy-examination of stomach, colposcopy-examination of cervix, laparoscopy-examination of abdominal cavity, etc. During endoscopy, physician performs a visual examination of organ surface and makes decision about diagnosis, possible biopsy; also he can perform surgical interventions (endo-surgery).

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Image Enhancement Techniques

Image enhancement refers to the process of highlighting certain information of an image, weakening or removing any unnecessary information according to specific needs. (Chris, 2010) Some of image enhancement are eliminating noise, revealing blurred details, and adjusting levels to highlight features of an image. (Gonzalez, 2002) Image enhancement can be made by using linear and non-linear filters. In linear filters, arithmetic mean filter, harmonic mean filter and contraharmonic mean filter can be used for noise removal. In non-linear filters, median filter can be used for noise removal. For contrast level enhancement, gamma correction filter that is under non-linear filter can be used. For sharping image, unsharp masking filter can be used that is under linear filters.

Linear Filters

Linear filtering modifies an image *"f" by* replacing the value at each pixel with some linear function of the values of nearby pixels. (Castleman, 1996) Spatial linear filtering is the filtering operations that are performed directly on the pixels of an image.

Common linear filters are:

a. Arithmetic mean filter
b. Unsharp masking filter
c. Harmonic mean filter
d. Contraharmonic mean filter

a. Arithmetic Mean Filter

Arithmetic mean filter calculates the average value in a set of pixel values. In other words, summing up all pixel values within the set and divide them by the size of that set. (Jae, 1990) The principle of this filter matches perfectly with it name, as each pixel in the targeted image is replaced with the mean value of pixels surrounding it. The mathematical formulation for the mean filter is given by:

$$f(x.y) = \frac{1}{MN}\sum_{(m,n)\in W} I(m,n)$$

where: I = the noisy image, f = the restored image and (m, n) = the row and column coordinate respectively, within a window W of size $m \times n$ where the operation takes place centered on input pixels at (x, y).

b. Unsharp Masking Filter

Unsharp mask filtering is method that boosts the high frequency edge information in images. (Jaehne, 2005) The unsharp masking process consists of the following steps:

Step 1. Blur the original image

Step 2. Subtract the blur image from the original (the difference is called the mask)

Step 3. Add the mask to the original

$\bar{f}(x,y)$ denoted the blurred image, the mask in equation form is given by:

$$g(x,y)_{mask} = f(x,y) - \bar{f}(x,y)$$

Then, add a weighted portion of the mask back to the original image:

$$g(x, y) = f(x, y) + kg(x, y)_{mask}$$

where include a weight, k ($k \geq 0$), for generality. When k=1, this process has unsharp masking.

c. Harmonic Mean Filter

Let S_{xy} represent the set of coordinates in a rectangular sub-image window of size $m \times n$, centered at point (x, y). The harmonic mean filtering operation of the restored image is given by the expression:

$$\hat{f}(x, y) = \frac{mn}{\sum_{(r,c)\in S_{x,y}} \frac{1}{g(r, c)}}$$

d. Contraharmonic Mean Filter

The contraharmonic mean filtering operation yields a restored image based on the expression:

$$\hat{f}(x, y) = \frac{\sum_{(r,c)\in S_{x,y}} g(r, c)^{Q+1}}{\sum_{(r,c)\in S_{x,y}} g(r, c)^{Q}}$$

where Q is called the order of the filter. Note that the contraharmonic filter reduces to the arithmetic mean filter if Q=0, and to the harmonic mean filter if Q = -1.

Non-Linear Filters

Non-linear filters, all filters which are not linear- are more diverse and difficult to categorize. (Russ, 1995) Non-linear spatial filter also operates on neighborhoods.

Common non-linear filters are:

a. Gamma Correction Filter
b. Median filter

a. Gamma Correction Filter

Gamma correction controls the overall brightness of an image. Power law transformation has the general form

$$s = cr^{\gamma}$$

where s and r are the output and input pixel values, respectively, c and γ are the positive constants. (Astola, 1997) Gamma can be any value between 0 and infinity. If γ is 1 (the default), the mapping is linear. If gamma is less than 1, the mapping is weighted toward higher(brighter) output value. If γ is greater than 1, the mapping is weighted toward lower(daker) output value.

b. Median Filter

The median filter operates by sorting the pixel values within a neighborhood, then finding the median value from that ordered list and the replacing the original pixel by this median value in output image. The mathematical formulation for median filter is given as follows:

$$f(x, y) = median\,\{I(m, n)|(m, n) \in W\}$$

where I = noisy image, f = restored image and (m, n) = row and column coordinate respectively, within a window W of size $m \times n$ where the operation takes place. (Russ, 2007)

Design of the Proposed System

The proposed system is designed to enhance the medical endoscopic image. For noise removal, in the need of the system, the original endoscopic image is added two types of noise that are Gaussian and Salt & Pepper noise. Noisy image is filtered using arithmetic mean, contraharmonic mean, harmonic mean and median filter methods.

For the contrast level controlling, the original image is inputted and that image is filtered using unsharp masking and gamma correction filter. The output image and input image are accessed by using Image Quality Assessment (IQA). Image Quality Assessment will include Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), and Structural Similarity Index Method (SSIM). Figure 1 show the architecture of the image filtering for proposed system.

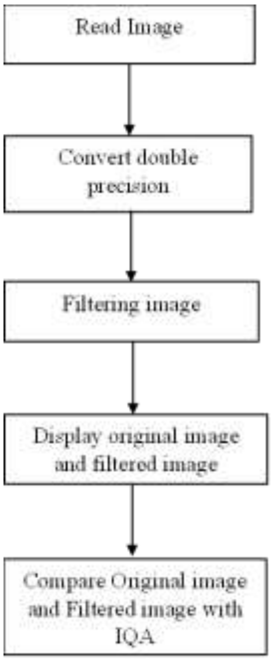

Figure 1 Architecture of the Image Filtering of the Proposed System

The general architecture of the proposed system is shown in Figure 1. The following steps are involved in architecture of the proposed system:

Step 1. Reading the input image
Step 2. Converting the input image into double precision
Step 3. Filtering process of the inputted endoscopic image
Step 4. Showing the original image and filtered image
Step 5. Comparing the original image and filtered image by Image Quality Assessment

Implementation of the Proposed System

The image processing toolbox is distributed by MathWorks that contains a collection of functions for performing different operation specifically for signal and image processing. If "Load Image" button is clicked in the form, dialog box will appear to choose the input image. Endoscopic image enhancement system is shown in Figure 2.

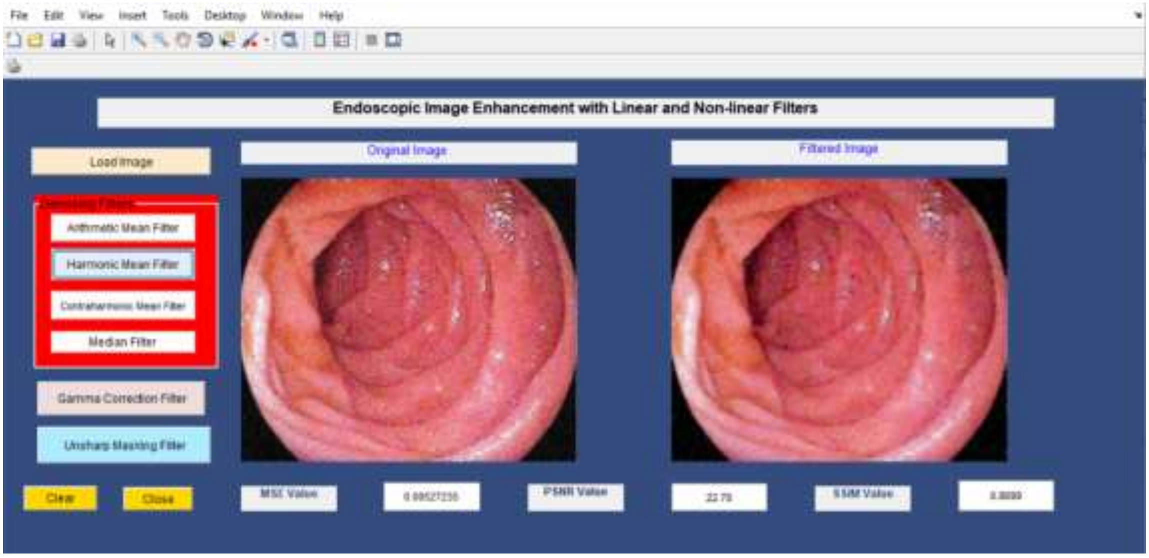

Figure 2 Endoscopic Image Enhancement for Proposed System

Figure 3 Endoscopic Image

Figure 4 Endoscopic Image with Gaussian Noise Level 0.01

Figure 5 Endoscopic Image with Salt & Pepper Noise Level 0.01

Figure 3 shows the endoscopic image. Figure 4 shows the endoscopic image with 0.01 gaussian noise. The endoscopic image with 0.01 salt & pepper noise is shown in Figure 5. For image noise testing, the original image is added salt and pepper noise with changing noise density. In adding noise, **imnoise** function is used. In salt and pepper noise, noise levels are tested from 0.001 to 0.05. For another noise testing, the original image is added gaussian noise with changing noise density. In gaussian noise, noise level is tested from 0.01 to 0.25.

The simulation for edge enhancement is based on the unsharp masking theory. This filter does not need noisy image to input because the characteristic of this filter is sharping the edge. In this simulation program, scaling constant numbers 0.2, 0.5, 0.8, 1.1, 1.4 have been used. Initially the input image is needed to load from the location of the stored files. Constant number must be entered from input box to apply the filter.

In the harmonic mean and contraharmonic mean filter, the color value of each pixel is replaced with the harmonic mean of color values of the pixels in a surrounding region. These filters will be tested by adding gaussian noise and salt and pepper noise with changing variable and sigma.

In gamma correction filter, endoscopic image is inputted from the location of stored files. This filter does not need to add noise because gamma correction controls the overall brightness of the inputted image. The value of gamma is assigned in this simulation program. The inputted image is adjusted using gamma value.

The median filter operates by sorting the pixel values within the neighborhood, the median value within the window replaces the original value. In this simulation program median filter will be tested for noise removal. First, the noisy image due to Gaussian or Salt& Pepper noise are inputted and he inputted image is filtered by splitting three color channels.

Result and Discussion

Image quality can be assessed using two methods: subjective and objective. Subjective methods are based on the perceptual assessment of a human viewer about the attributes of an image, while objective methods are based on computational models that can predict perceptual image quality. In the endoscopic image evaluation, doctor's subjective evaluation is still the main technique that is used to verify image quality. In this system, to verify the performance of tissue vascular, brightness, and color enhancement, image quality assessment is defined as: (1) mean square error (MSE) (2) peak-signal-to-noise ratio (PSNR) (3) structural similarity index (SSIM).

The proposed system aims for enhancing the image. For noise removal, the proposed system needs to test noise level with image quality assessment. First, the original image is added with gaussian noise. When the gaussian noise level are increased from 0.01 to 0.25, the values of MSE are increased and PSNR values are decreased. The values of SSIM are decreased from 1. When the salt and pepper noise level are increased from 0.001 to 0.05, the values of MSE are increased and PSNR values are decreased. The values of SSIM are decreased from 1. Figure 6 shows the graph diagram of Gaussian noise range from 0.01 to 0.25. Figure 7 illustrates the diagram of Salt and Pepper Noise Range from 0.001 to 0.05.

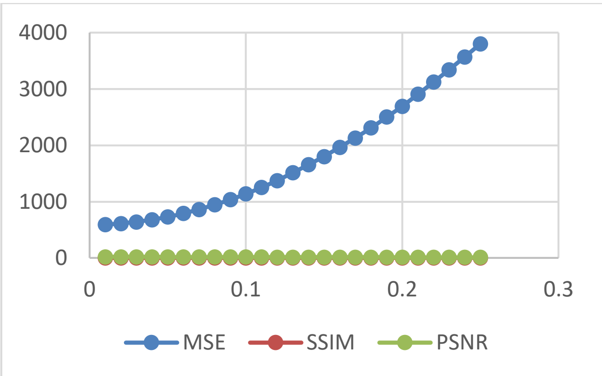

Figure 6 Graph Diagram of Gaussian Noise Range from 0.01 to 0.25

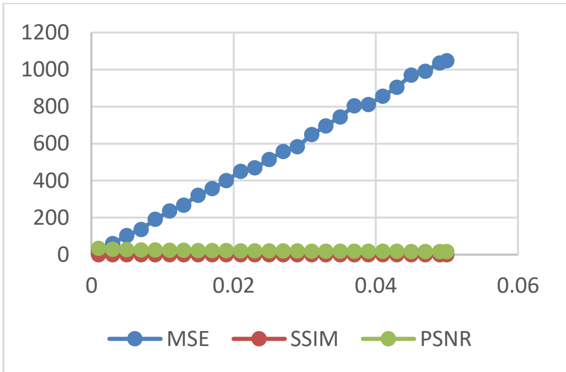

Figure 7 Graph Diagram of Salt and Pepper Noise Range from 0.001 to 0.05

After applying the arithmetic mean filter to the various gaussian noise level image, the values of MSE are significantly decreased. The values of PSNR are increased and SSIM values are closely increased to 1. Figure 8 shows Gaussian Noise Level after Arithmetic Mean Filter with 2×2 Window Size applied. The results of the metric values for salt and pepper noise level after applying arithmetic mean filter is shown as diagram in Figure 9. Figure 10 show the size 2x2 arithmetic mean filter window applied over gaussian noise 0.01. Figure 11 also show the arithmetic mean filter with window size 2x2 applied over salt & pepper noise 0.01.

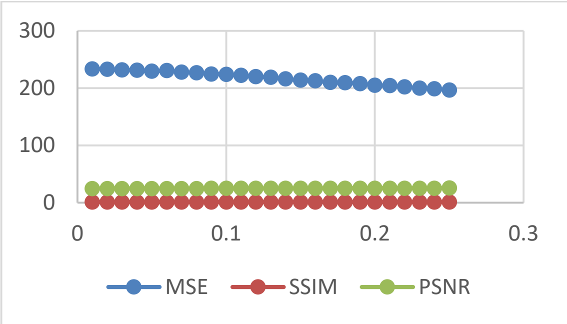

Figure 8 Gaussian Noise Level after Arithmetic Mean Filter with 2×2 Window Size applied

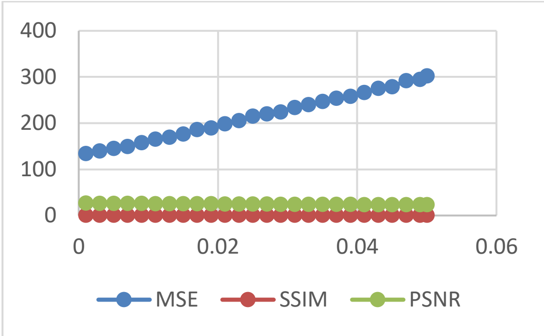

Figure 9 Salt & Pepper Noise Level after applying Arithmetic Mean Filter with 2×2 Window Size

Figure 10 Applied Arithmetic Mean with Size 2 Window over Gaussian Noise 0.01

Figure 11 Applied Arithmetic Mean with Size 2 Window on Salt & Pepper Noise 0.01

After applying the unsharp masking filter to the original image by changing the constant number from 0.2 to 1.4, the values of MSE are increased and SSIM values are decreased. If scaling constant number is over 1.5, endoscopic images likely contain some noises. Figure 12 illustrates the metric values for Unsharp Masking Filter. Figure 13 shows the unsharp masking filter with constant 1.4.

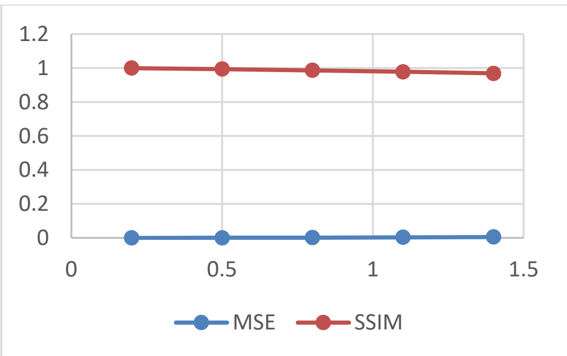

Figure 12 Graph Diagram of Metric Values for Unsharp Masking Filter

Figure 13 Applied Unsharp Masking Filter with constant 1.4

After applying harmonic mean filter to the gaussian noise, the value of MSE significantly decrease from 593.8053 to 0.0033. Therefore, error value decreases over 500. The value of SSIM increases from 0.8256 to 0.9332. The value of PSNR also increase from 20.3944 to 24.7892. After applying the harmonic mean filter to the various salt and pepper noise level images, the values of MSE are significantly decreased. The values of PSNR are decreased and SSIM values are decreased from 1. Figure 14 shows the diagram of Metric Values for Harmonic Mean Filter with Variable Sigma of Gaussian Noise. Figure 15 shows the metric values for Harmonic Mean Filter with Variable Density of Salt and Pepper Noise. Figure 16 illustrate the result of harmonic mean filter over gaussian noise 0.01. Figure 17 also demonstrates the result of harmonic mean filter over salt & pepper noise 0.01.

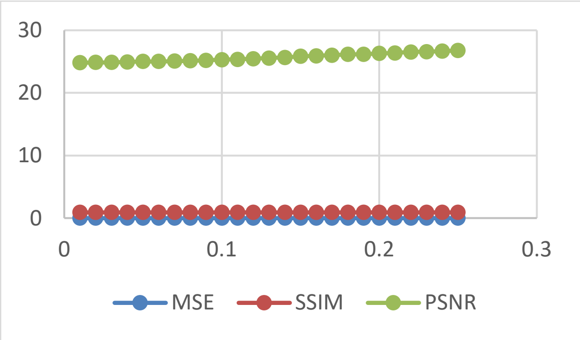

Figure 14 Diagram of Metric Values for Harmonic Mean Filter with Variable Sigma of Gaussian Noise

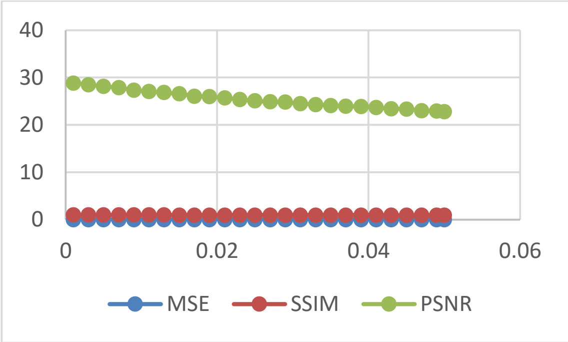

Figure 15 Metric Values for Harmonic Mean Filter with Various of Salt and Pepper Noise

Figure 16 Harmonic Mean Filtered Image Over Gaussian Noise 0.01

Figure 17 Harmonic Mean Filtered Image Over Salt & Pepper Noise 0.01

After applying contraharmonic mean filter to the gaussian noise, the value of MSE decrease from 593.8053 to 0.0033. The value of SSIM increase from 0.8256 to 0.9411. The value of PSNR also increase from 20.3944 to 24.8386. After applying contraharmonic mean filter to salt and pepper noise, MSE value decrease from 21.0299 to 0.0016. SSIM value decrease from 0.9918 to 0.977. PSNR value also decrease from 34.9024 to 28.0764. Figure 18 demonstrate the metric values for Gaussian noise after applying contrahoarmonic mean filter. Figure 19 shows metric values for salt and pepper noise after applying contraharmonic mean filter. Figure 20 shows the result of contraharmonic mean filtered over gaussian noise 0.01. Figure 21 shows the result of contraharmonic mean filtered over salt & pepper noise 0.01.

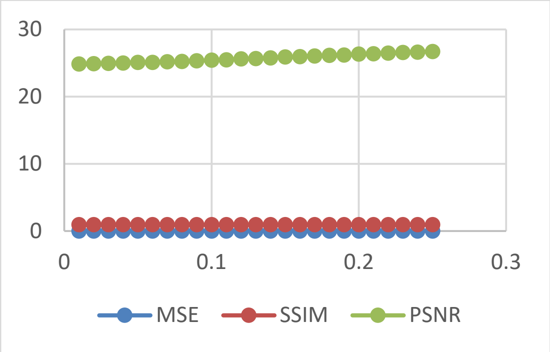

Figure 18 Metric Values for Gaussian Noise after Contraharmonic Mean Filtered

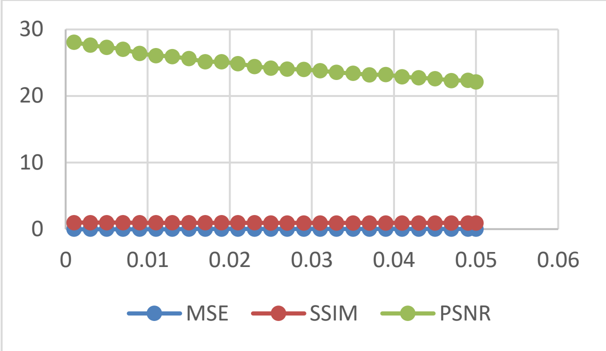

Figure 19 Metric Values for Salt and Pepper Noise after Contraharmonic Mean Filtered

Figure 20 Contraharmonic Mean Filtered Image Over Gaussian Noise 0.01

Figure 21 Contraharmonic Mean Filtered Over Salt & Pepper Noise 0.01

After applying the gamma correction filter to the original image by changing the gamma value from 0.5 to 1.5, the values of the MSE are decreased and SSIM values are increased. When the gamma value is 1, the values of MSE 0 and SSIM value is perfectly 1. When gamma value is less than 1, endoscopic images will brighter. When gamma value is greater than 1, endoscopic images will darker. Figure 22 shows the diagram of the metric values of gamma correction. Figure 23 illustrates the gamma correction filtered with gamma value 1.2.

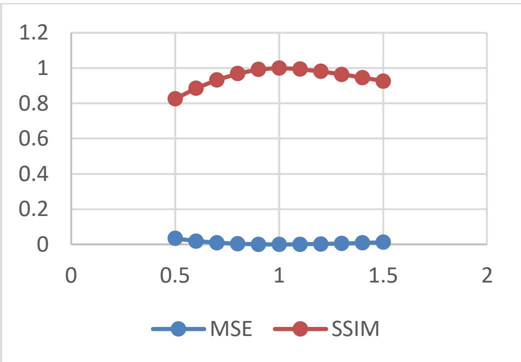

Figure 22 Diagram of the Metric Values of Gamma Correction with MSE and SSIM

Figure 23 Gamma Correction Filtered with Gamma Value 1.2

After applying median filter to the gaussian noise, the value of MSE decrease from 593.8053 to 145.9388. The SSIM value increase from 0.8256 to 0.9533. The PSNR value also increase from 20.3944 to 26.4891. After applying median filter to salt and pepper noise, MSE value decrease from 21.0299 to 16.5762. SSIM value slightly increase from 0.9918 to 0.9941. PSNR value also increase from 34.9024 to 35.936. Figure 24 shows the diagram of the metric values of various Gaussian noise level image after applying median filter. Figure 25 demonstrates the diagram of the metric values of various salt and pepper noise level image after applying median filter. Figure 26 shows the result of median filtered over gaussian noise 0.01. Figure 27 shows the result of median filtered over salt & pepper noise 0.01.

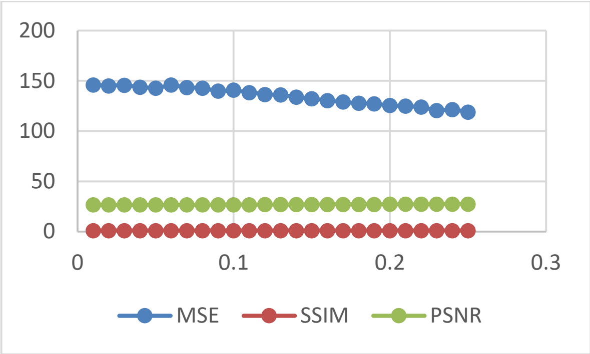

Figure 24 Metric Values of Gaussian Noise Level Image after Applying Median Filter

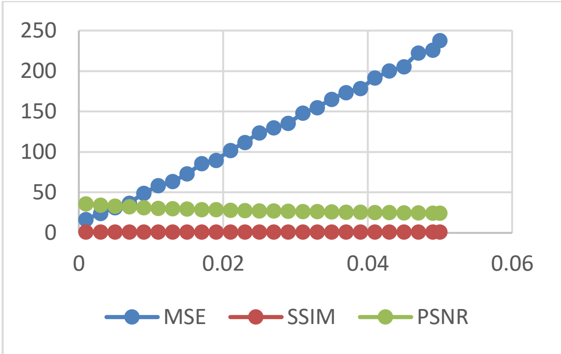

Figure 25 Metric Values of Salt & Pepper Noise Level after Applying Median Filter

Figure 26 Median Filtered Image on Gaussian Noise 0.01

Figure 27 Median Filtered Image on Salt & Pepper Noise 0.01

When the noise level increases, the original image becomes vague. Gaussian noise level is tested from 0.01 to 0.25. Salt and pepper noise density is tested from 0.001 to 0.05. Table 1 shows the IQA values of Gaussian noise level 0.01 and salt & pepper noise level 0.001. Table 2 shows the comparison of denoising filter IQA values after removing Gaussian noise level 0.01. Table 3 also shows the comparison of denoising filter IQA values after removing salt and pepper noise level 0.001.

Table 1. IQA Values of Gaussian Noise Level 0.01 and Salt & Pepper Noise Level 0.001

Type of Noise	MSE	SSIM	PSNR
Gaussian Noise	593.8053	0.8256	20.3944
Salt & Pepper Noise	21.0299	0.9918	34.9024

Table 2. Comparison of Each Denoising Filter IQA Values after Removing Gaussian Noise 0.01

Type of Denoising Filters	MSE	SSIM	PSNR
Arithmetic Mean Filter	233.3288	0.9332	24.4511
Harmonic Mean Filter	0.0033	0.9358	24.7892
Contraharmonic Mean Filter	0.0033	0.9411	24.8386
Median Filter	145.9388	0.9533	26.4891

Table 3 Comparison of Each Denoising Filter IQA Values after Removing Salt & Pepper Noise Level 0.001

Type of Denoising Filters	MSE	SSIM	PSNR
Arithmetic Mean Filter	134.3917	0.9631	26.8471
Harmonic Mean Filter	0.0013	0.9784	28.8166
Contraharmonic Mean Filter	0.0016	0.977	28.0764
Median Filter	16.5762	0.9941	35.936

Arithmetic mean filter, harmonic mean filter and contraharmonic mean filter work better when removing Gaussian noise compared to removing the salt and pepper noise. Median filter is introduced to overcome the limitation of type of mean filter; therefore, it works better when removing salt and pepper noise comparing to removing Gaussian noise. But median filter not only remove the noise but also preserve the edges of image. For noise removal, only small size of window is considered to use for removing noise. This can see when the bigger size of window is applied the image tends to become more blurred when the filtering job is done.

Gamma correction filter, different gamma values are compared from 0.5 to 1.5 for color contrast enhancement. When gamma value is 1, the color of the original image will not be changed. When gamma value is greater than 1, the color of the image will darker. When gamma value is less than 1, the color of the image will brighter.

Unsharp masking filter, different scaling factors are compared to find scaling factor that gives the best enhancement of the edges in the image. The k value is measured from k=0.2 to 1.4. The scaling constant 0.8 is chosen because the edge is enhanced nicely without amplify the false edge(noise). The false edge can be found on when k =1.4 compared to the original image.

Conclusion

In conclusion, different filters have different strengths and weaknesses. Different types of filters are needed when solving image processing problems. Sometimes a nonlinear filter may work better than a linear filter. In image restoration, the nonlinear filters can be filtered than linear filters. While the linear filter can remove the noise, the nonlinear filter not only removes the noise but also can preserve edges. Because a single filter is no needed to remove noise, but a range of filters are needed, depending on the situation encountered.

Linear for specific endoscopic image processing tasks were analyzed: arithmetic mean filter, unsharp masking filter, harmonic mean filter, contraharmonic mean filter as a linear filter type. Nonlinear filter for endoscopic image processing tasks were analyzed: gamma correction filter and median filter as a nonlinear filter type. The requirements of the filters to remove unwanted artefacts(noise) and to enhance edge and to control contrast level of image were identified. By using this research in medical field, physicians can improve to decide the diseases.

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