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A Study on Denoising of Poisson Noise in Pap Smear Microscopic Image

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Abstract

Objectives: To study and implement various spatial domain denoising filters on various Pap Smear microscopic images. **Methods/Statistical Analysis:** In this paper, we calculated the performance metrics to estimate best fit filtering technique among the filters considered for this study. Study of around 300 microscopic Pap Smear images with low and high color densities are considered which includes images from two different standard slide preparation techniques i.e. Conventional Based Cytology (CBC) and Liquid Based Cytology (LBC). Performance of different filters is analyses based on performance metrics like PSNR, MSE, NAE and SNR. **Findings:** Poisson noise is more likely in Pap Smear images as it is captured using CCD camera at microscopic eye piece. From this study it was found that adaptive wiener filter can be used to reduce Poisson noise in both LBC and CBC Pap Smear Microscopic image. **Application/Improvements:** This helps to improve analysis result for pathologists using computer aided diagnosis system.

Keywords: Denoising, Microscopic Image, Pap Smear, Performance Metrics, Poisson Noise

1. Introduction

The Papanicolaou (Pap) Smear method is a medical procedure to detect infections and precancerous cells in the human cervix. Pap Smear is the primary screening test for cervical cancer, which is one of the most commonly found in countries like India, U.S.A., U.K., Thailand, Malaysia etc. It involves examining cervical cells under microscope to find abnormality if any. Cervical cancer can occur due to abnormal cells left untreated in the transformation zone of the cervix. Pap Smear test can identify those cells which are potential to change as cancerous in the initial stage and helps to diagnose the patient before it turns into cancer. Pap Smear test involves a clinical procedure to collect cervical cells and mount them on the microscope slides by applying Pap stain. The pathologists analyze these slides by keeping under microscope. This is exhaustive, tiresome, time consuming and sometimes interpretation varies from person to person. This manual interpretation is challenging due to over staining which varies the features of cells like its contrast, texture and color-density[1]. It is difficult sometimes when there are too many unwanted biological debris in the background like dendrites, lymph cells, blood cells which can lead to confusion between them and actual cervical cells[2].

The quality of the image depends on how the slide samples are prepared. In this regard, there are mainly two ways of preparing the slide. First one is Conventional Based Cytology (CBC) Pap Smear in which samples collected are placed on the microscopic glass slides, pap stains are applied. The process of staining differs due to manufacturers, procedure and way of storing slides. Images obtained can be degraded from varying illumination due to these stains. Results and interpretation are difficult due to irregularities in the preparation of slides and overlapping cells[2].

Background in this sample contains more biological noises, the chances of hyperchromatic images are more due to uneven distribution of stains. An image obtained from this kind of samples need to be filtered and enhanced further. The second method of slide preparation is called Liquid Based Cytology (LBC) in which a specific device is used to prepare Pap Smear slides. Here, the collected samples are deposited in the bottle of preservative liquid. This liquid is treated and other biological debris is removed. Then those cells are applied to the glass slide.

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This results in monolayer of cells[1]. Samples obtained from this are free from background biological noises. As a result, images obtained from these samples are clearer in the background without much noise. Hence, possible noise in these images is mostly device dependent noise rather than biological debris. These images require very less effort in filtering and enhancement. The preprocessing of Pap Smear images can also be done using morphological operations. Biological noises are removed based on color intensity level and area features[2].

To overcome these non-uniformity, challenges and variations in an analysis of slides in the above-mentioned methods, computer aided automated system is used to analyse Pap Smear samples. This involves capturing Pap Smear image using CCD camera and light microscope with known resolution and apply suitable image processing techniques which segments, extracts features helpful for identifying normal and abnormal cells. Again, a decision made by such computer aided system can vary due to noise(s) induced by acquisition device (non-biological noise) and also biological noise. Hence, it is necessary to remove noises and enhance the quality of the image, before their features are extracted[3]. The biological noises can be removed using morphological operations whereas non-biological noises are removed using filtering techniques. Non-biological noise(s) found in Pap Smear images are because of uneven lighting due to varying photon energy along the surface of slide, poor contrast due to the insufficient light from the source, blurring of image due to different magnification, varying types of microscopes which will degrade the image of Pap Smear sample. Sometimes, the non-biological noises in Pap Smear microscopic image are device-dependent noises which depend on the type of microscope used. Pap Smear method uses optical or light microscope which produces an image of slide using photon/light energy[4]. Hence, Poisson noise or shot noise is mostly likely in Pap Smear cervical cell images which are added due to the non-uniform distribution of photons. Poisson noises are induced due to discrete nature of electrical charges. They depend on photon count and nature of light. This noise is dominant when a number of energy particles is sufficiently small[5,6]. Denoising is carried out using various filtering methods like Wiener, Average, Disk, Gaussian, Motion, LoG, Laplacian, Median, Adaptive wiener, Lucy-Richardson, Regularized and so on. The performance of the filter is evaluated based on metrics like PSNR, MSE, SNR, RMS values for each denoised image. The selection of filter depends on the nature of noise present in the image[7].

In this study, we considered Poisson noise on cimages. In this paper, we study the best fit filter which reduces Poisson noise in Pap Smear microscopic image depending on their performance metrics.The Poisson noise is removed by various operations like smoothing, sharpening and edge enhancement filtering methods. Many authors published different denoising filters to deal with Poisson noise. In a study, author has analyzed Pap Smear cervical cell image by inducing impulsive noise with varying error percentage in the difference of 5 and they could attain PSNR values in between 10 to 25 using bi-group enhancement. Also, nucleus area is dominantly visible. The adaptive median filter was used to remove the noise and also, analysis of the performance of hybrid bi-group enhancement was done on both noisy and noiseless image[8]. Another study says, Laplacian of Guassian (LoG) filter when applied during segmentation of nuclie from cell, performed well compared to others as it highlights regions of edges (region where rapid intensity change occurs). This filter generated positive gradient values inside the region of nuclei. This was because nuclei region is darker compared to background[9]. Author published a paper in which denoising of Pap Smear image is done using Wiener filter, Lucy Richardson filter and regularized filter. It is found that Wiener filter efficiently removed Poisson noise compared to all other filters and also it enhanced the visual quality of the image[10].

2. Denoising

Preprocessing of Pap Smear image involves removing unwanted background information within it. There are two region of interest in this image, one is nucleus region and other is cell region. Filters required to denoise these image should blur or suppress background pixels and enhance the ROI(s) which further improves the result of segmentation. Also, quality of image will be degraded by either under staining or over staining, uneven lighting across the surface of slide. As we know that quality of image and background noise depends on the type of Pap Smear slide preparation. That is, less background noise in liquid based preparation compared to conventional slide preparation. We considered Pap Smear microscopic images with 60X magnification of both liquid based and conventional method for the study. Various noise models and filtering schemes are described by various authors and different metrics are used to find the suitability of the techniques. The noise model, filtering techniques and performance metrics considered in this study are as discussed in Sections 2.1 and 2.2 respectively.

2.1 Poisson Noise

The microscopic images are more tendencies to be degraded by Poisson noise. This is an electronic noise produced when finite number photons are small enough to give detectable statistical fluctuations[6,11]. Here, photons plays a significant role. A single photon at $\lambda = 500$ nm carries energy of $E = hv = hc/\lambda = 3.97 \times 10^{-19}$ J. Noises in CCD cameras are due to statistical nature of photon production. The number of photons in given two consecutive pixels will not be same. The probability distribution for P (n) for n photons in an observation window of length T seconds is as follows:

$$P(n|\rho, T) = \frac{(\rho T)^n e^{-\rho \tau}}{n!} \tag{1}$$

Where ρ is the rate or intensity parameter measured in photons per second. The statistical fluctuations with photon when counted over finite time interval T will lead to finite Signal-to-Noise Ratio (SNR)[12]. Poisson noise will occur when there is insufficient amount of photons found in statistical information identified by the sensor. In Poisson noise, signal gets more corrupted with varying proportions and it also depends on the type of sensor used[13].

2.2 Filtering Techniques

The main goal of filtering is to enhance the quality and appearance of an image. This has a major impact on the result of automated image processing. There is a requirement for processing tools for spatial domain technique with very less computation time. So, spatial domain techniques using transformation, histogram-based were reviewed and found that wiener filter is suitable and removed all kinds of noises. The following are some of the filters applied in this study on the input image in (m, n) to get filtered image g(x, y).

2.2.1 Gaussian Filter

This filter uses Gaussian convolution function (kernel) with specific size on a given image. The default size of kernel is 3 x 3. The 2-D circular symmetric Gaussian has the following form:

$$g(x, y) = \frac{1}{2\pi\sigma^2} e^{\frac{-x^2+y^2}{2\sigma^2}} \tag{2}$$

2.2.2 Average Filter

This filter replaces each pixel by the average of the pixels in a square window surrounding the pixel. Extends the idea of moving average for images. This means that the mask is constant. Averaging filters is suitable for image in which pixel value changes slowly but noise is a wide band signal. This filter blurs image edge and other details. This is a low-pass filter. The new pixel values are calculated as per formula given below:

$$g(x, y) = \frac{1}{mn} \sum_{k \in m} \sum_{l \in n} in(k, l) \tag{3}$$

Where, mXn is size of region of pixel (usually m = n), mn is the normalization factor, this preserves the range of values in original image.

2.2.3 Disk Filter

A disk filter is a type of average filter which uses circular approximation of values.

2.2.4 Laplician Filters

This is a second derivative edge enhancement filter. This operates irrespective of edge direction. It highlights maximum value within the image using kernel with high central value. This value is typically surrounded by negative weights in the north-south and east-west directions. ero values at the kernel corners. All Laplacian filters must have odd kernel sizes. The Laplacian L (x, y) of an image with pixel intensity values (m, n) is given by:

$$g(x, y) = \frac{\partial^2 in}{\partial m^2} + \frac{\partial^2 in}{\partial n^2} \tag{4}$$

2.2.4 Motion Filter

Motion filter approximates the linear values of camera.

2.2.5 Adaptive Spatial Filtering

Above discussed filters are applied to an image independent of how image characteristics which varies from one location to another. Hence, results can be improved if filters can adapt to these varying characteristics of image in the place where image is being filtered.

- Adaptive Median Filter**:** This is nonlinear spatial filter. It replaces gray level of an image by the median value of neighboring pixels. It is also built based on the statistics delivered from arranging the elements of a set rather than considering the mean value. This filter removes noise without affecting edges of original image. This is one of the best order statistic filter. The median is represented by the following equation:

$$\mathbf{g(x,y) = median_{(s,t)\in S_{xy}}\{in(m,n)\}} \quad (5)$$

The value of the pixel at m, n is considered for calculating median. When scanned over edge, this filter produces new realistic pixel values. So, this filter is better in preserving edges than basic median filter. The advantage of this filter is that it suppresses the uniform noise and also other noises.

- Adaptive Wiener Filter**:** Wiener filter is one of the best linear image restoration approach.

Wiener filter can attain significant noise removal when the noise variance is low. This in turn smoother and blur the sharp edges of image. For better performance, choose appropriate window value. The adaptive Wiener filter is expressed by the following equations.

$$\hat{\mathbf{x}}(\mathbf{i},\mathbf{j}) = \frac{\sigma_x^2(i,j).\,y(i,j) + \sigma_n^2.\,\bar{y}(i,j)}{\sigma_x^2(i,j) + \sigma_n^2} \quad (6)$$

$$\sigma_x^2(i,j) = \max\{0, \sigma_y^2(i,j) - \sigma_n^2\} \quad (7)$$

Where, $\hat{x}(i,j)$ is the filtered output at (i,j). σ_n^2 is the noise variance which is constant over the image and $y(i,j)$ and $\sigma_y^2(i,j)$ are the local mean and local variance of the input image y at (i, j). The output is calculated using the value of pixel at the centre and local statistics. Filtering is not constant for each pixel[9].

2.3 Performance Metrics

It is necessary to measure the amount of restoration after filtering which can make evident that which filter is most suitable for the nature of image and noise considered. For this, the following metrics are considered:

2.3.1 Signal-to-Noise Ratio (SNR)

SNR is a physical measure of sensitivity of imaging system which is measured in decibels (dB) of power. SNR is 32.04 dB for excellent image quality and SNR is 20 dB and above is acceptable image quality[10]. This is used to find how much signal is degraded by noise.

$$SNR = m/\sigma \quad (8)$$

Where, m is the mean and σ is the standard deviation of an image. The noise is stronger for lower valueofSNR. For good quality image, SNR value should be high.

2.3.2 Mean Square Error (MSE)

The average of squared of the errors are measured. This is the difference between estimator and estimated[10]. It is the sum of over all squared value of differences divided by size of image. It's a measure between the original image and the reconstructed image.

$$MSE = 1/MN \sum_{j=1}^{M} \sum_{k=1}^{N} [(I(x,y) - I'(x,y)]^2 \quad (9)$$

Where I (x, y) is the original image, I' (x, y) is the reconstructed image and M and N are the dimensions of the images. The low value of MSE signifies the good quality image.

2.3.3 Peak Signal to Noise Ratio (PSNR)

It is a measure of the peak error. It is the ratio between maximum power of signal and power of noise that corrupting the representation. PSNR value is expressed in terms of logarithmic decibel scale. The signal here is the original data and noise is the error induced. Higher PSNR generally indicates that the quality of reconstruction is high. PSNR (in dB) is defined in terms of MSE as follows:

$$\mathbf{PSNR = 10\log\left(\frac{255}{\sqrt{MSE}}\right)} \quad (10)$$

A low value of MSE signifies to less error and this is translated to high value of PSNR when relation between MSE and PSNR is reversed. The higher value of PSNR signifies that ratio of signal to noise is higher, as signal refers to original image and noise to error in reconstruction[11].

2.3.4 Normalized Absolute Error (NAE)

NAE is numerical difference between the original and reconstructed image. It is calculated using the formula below:

$$\mathbf{NAE} = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N}\left|X_j, k - X_j, k\right|}{\sum_{j=1}^{M}\sum_{k=1}^{N}\left|X_j, k\right|} \qquad (11)$$

Where, M x N is size of the image, Xj is the original image, k is the noisy image.

3. Results and Analysis

Two cases of images are mainly considered in this study. Case 1 is images obtained from Conventional Based Cytologic (CBC) Pap Smear and case 2 is Liquid Based Cytologic (LBC) Pap Smear. In each case, images with three different magnification like low, medium, high are considered. Also, images with low and high color densities are considered and performance of different filters are analysed based on performance metrics like PSNR, MSE, NAE and SNR. For each denoising technique, we have evaluated all performance metrics over 300 microscopic images of each type and average values are documented in corresponding tables. The Figures 1-8 and 13-20 shows output of different filters on images from Cases 1 and 2.

The Figure 1 is a sample original CBC image and Figures 2-8 are the corresponding output images from noise removal filters considered. The Figure 13 is a sample original LBC image and Figures 14-20 are the corresponding output images from noise removal filters considered.

It is evident from the performance metric values of six different filters are applied on around 300 images from CBC, LBC Pap Smear as shown in Tables 1 and 2 correspondingly. It is quiet evident that, comparatively adaptive Wiener filter has better values for performance metrics like PSNR, SNR, MSE and NAE as shown in Figures 9-12 and 21-24 for LBC.

These metrics are as follows; average PSNR for LBC is 26.56161, average MSE = 254.9973, average NAE = 0.049608, average SNR = 24.59059 found to have better values compared to other filters considered.

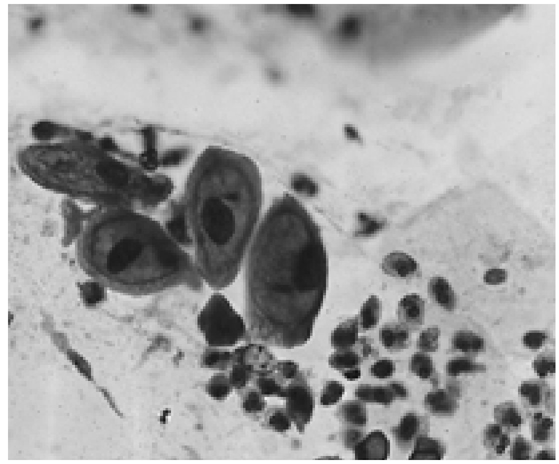

Figure 1. Conventional Pap high magnification image.

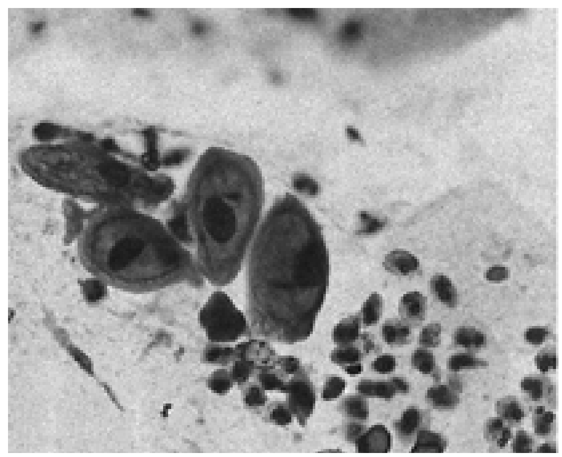

Figure 2. Conventional Pap high magnification image with Poisson noise.

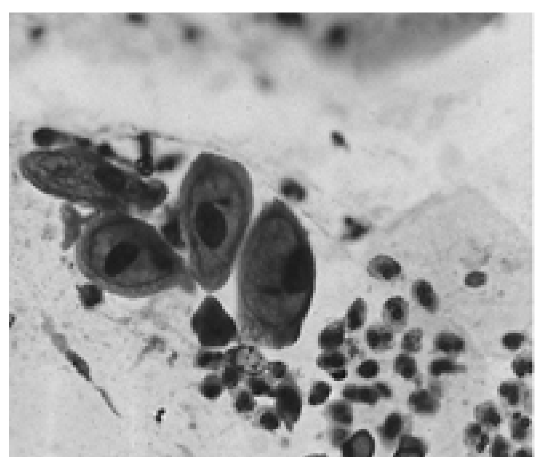

Figure 3. CBC low magnification Gaussian filtered image.

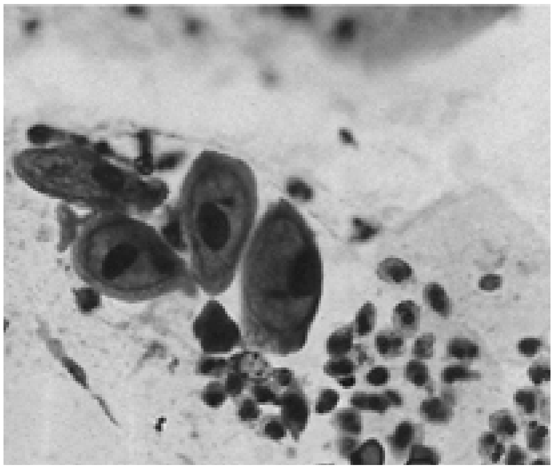

Figure 4. CBC high magnification motion filtered image.

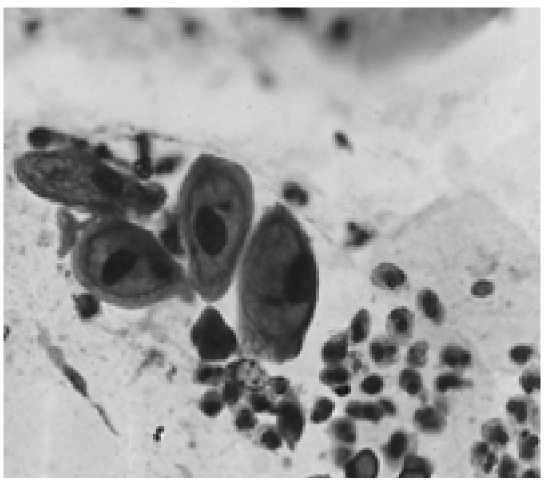

Figure 5. CBC high magnification filtered image.

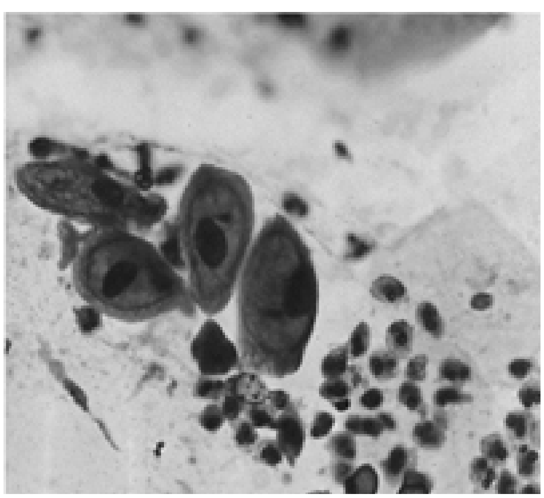

Figure 6. CBC high magnification average disk filtered image.

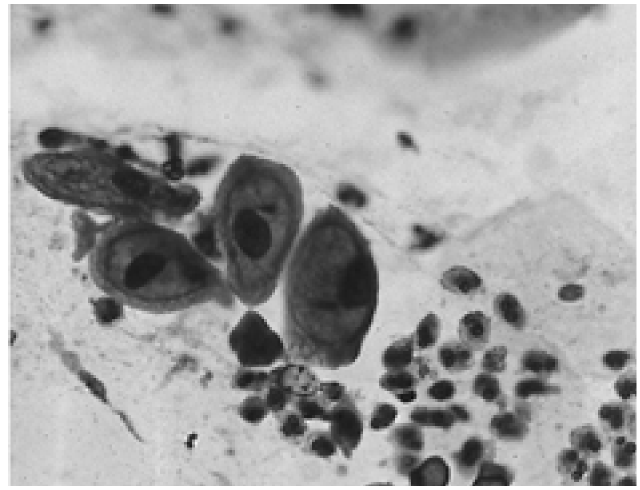

Figure 7. CBC high magnification adaptive Wiener filtered image.

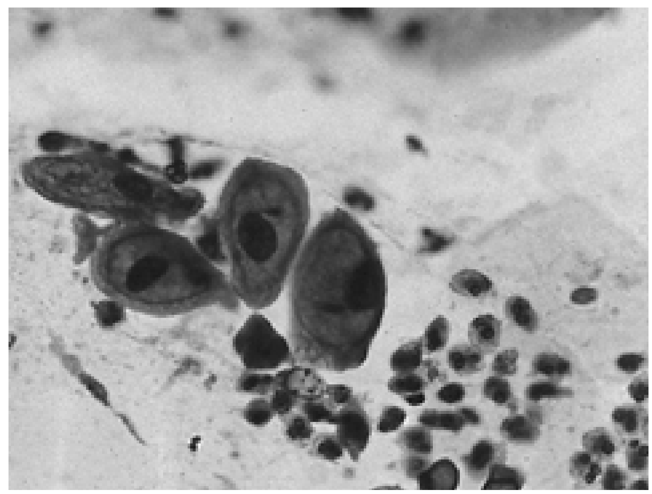

Figure 8. CBC high magnification adaptive median filtered image.

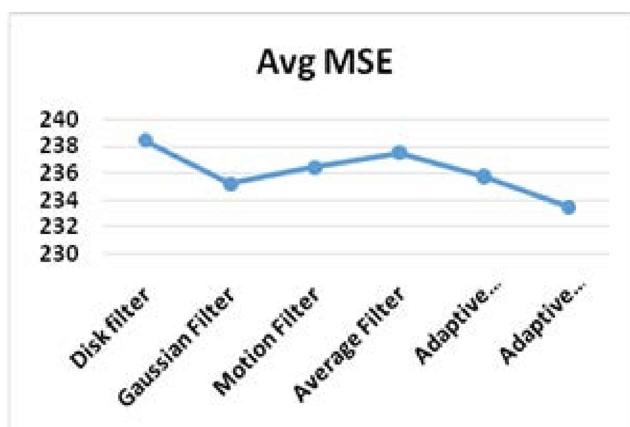

Figure 9. Graph of average PSNR vs. different Filters for conventional Pap Smear images.

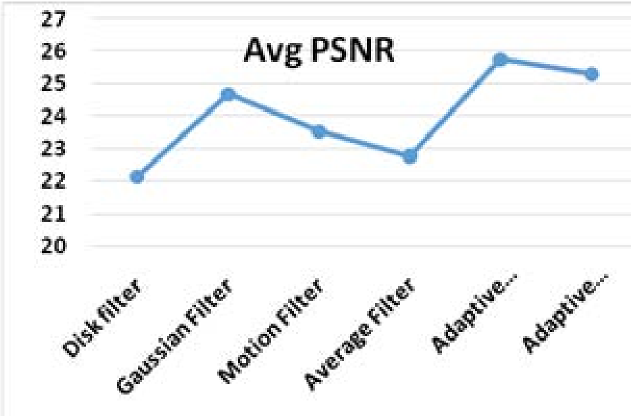

Figure 10. Graph of average MSE vs. different filters for conventional Pap Smear images.

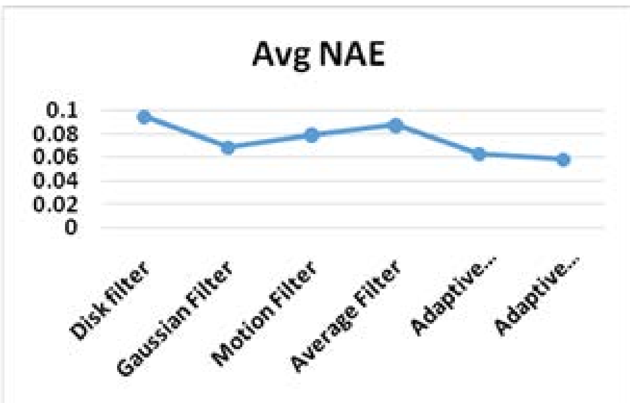

Figure 11. Graph of average NAE vs. different filters for conventional Pap Smear images.

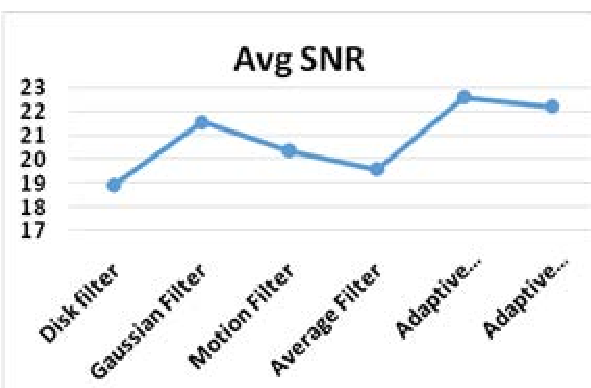

Figure 12. Graph of average SNR vs. different filters for conventional Pap Smear images.

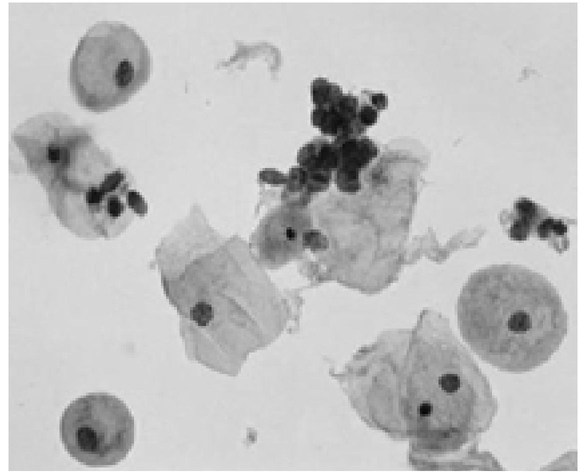

Figure 13. LBC high magnification image.

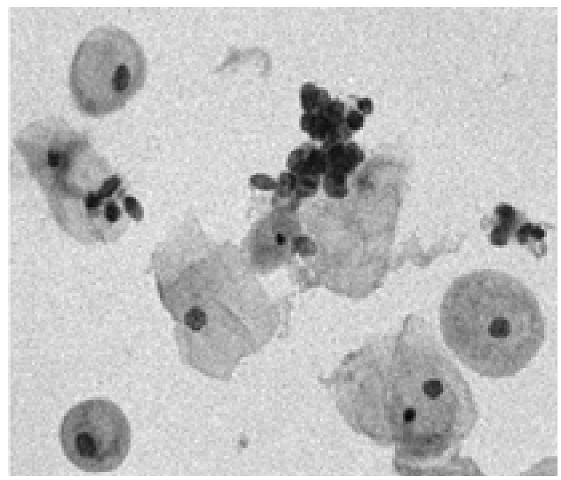

Figure 14. LBC high magnification Poisson noisy image.

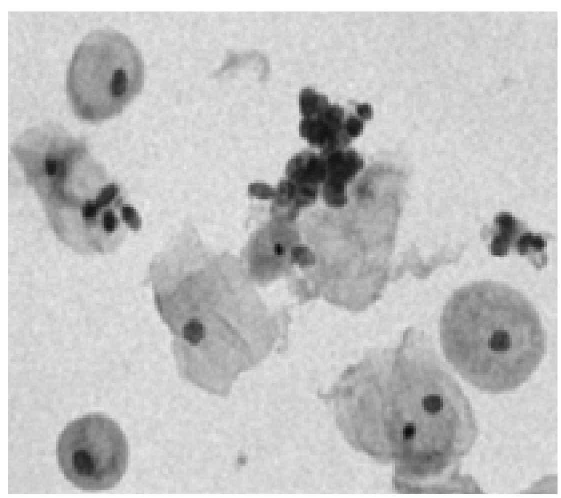

Figure 15. LBC high magnification Gaussian filtered image.

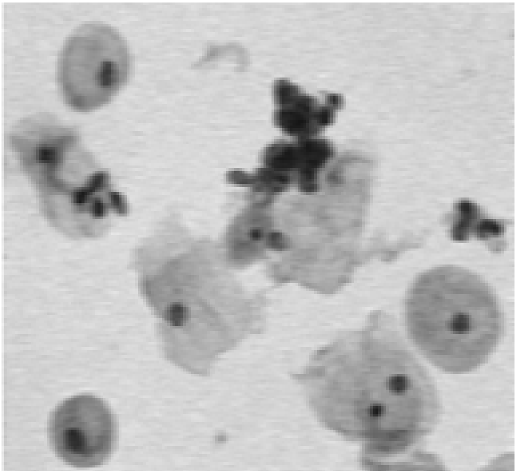

Figure 16. LBC high magnification motion filtered image.

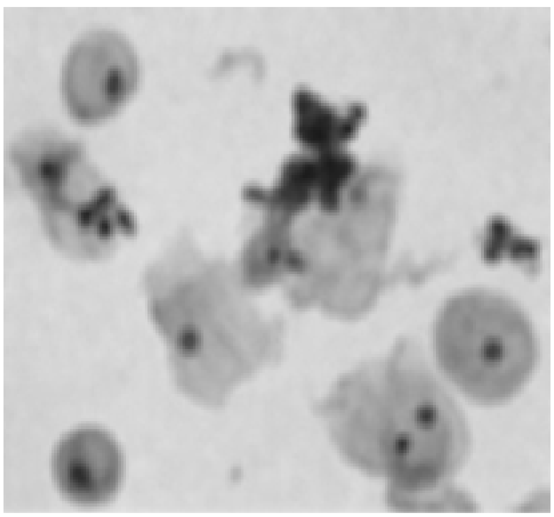

Figure 17. LBC high magnification Disk filtered image.

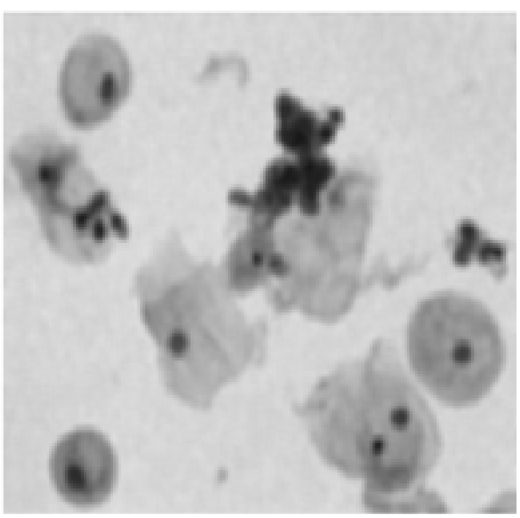

Figure 18. LBC high magnification average filtered image.

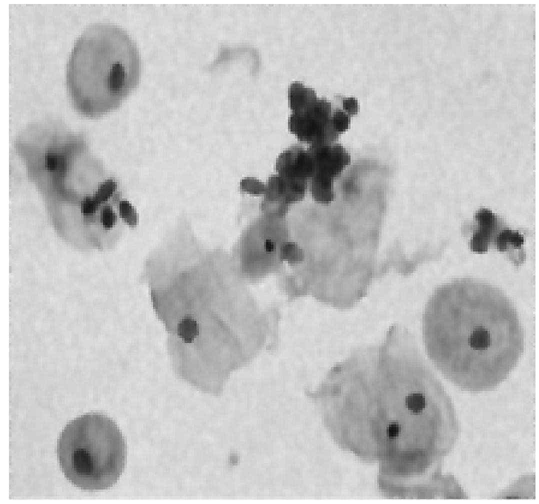

Figure 19. LBC high magnification adaptive Wiener filtered image.

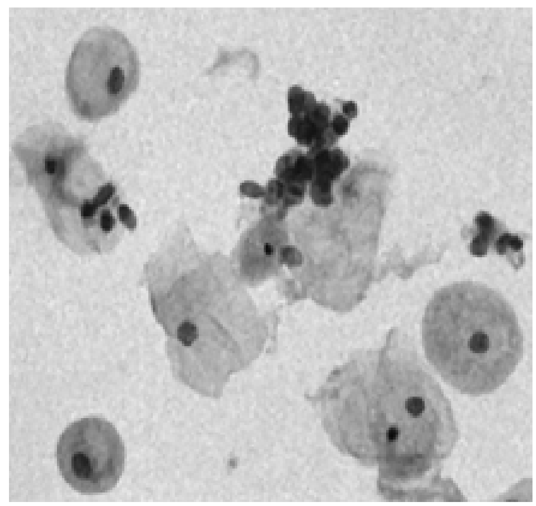

Figure 20. LBC high magnification Adaptive Median filtered image.

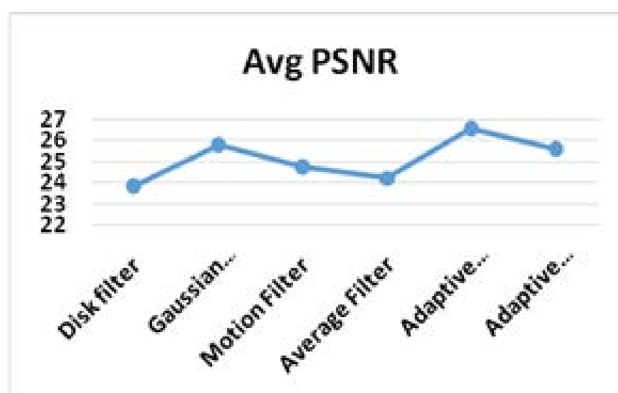

Figure 21. Graph of average PSNR vs. different filters for liquid based Pap Smear images.

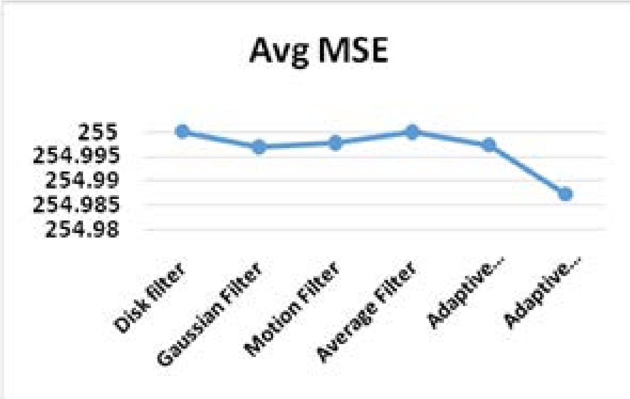

Figure 22. Graph of average MSE vs. different filters for liquid based Pap Smear images.

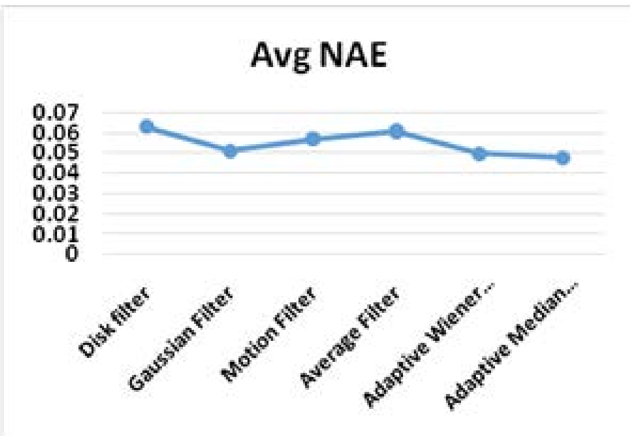

Figure 23. Graph of average NAE vs. different filters for Liquid based Pap Smear images.

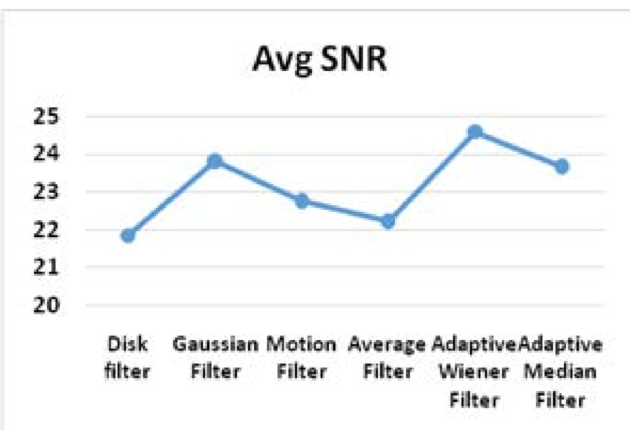

Figure 24. Graph of average SNR vs. different filters for liquid based Pap Smear images.

Table 1. Average performance metrics for conventional based cytologic Pap Smear images

Name of the Filter	PSNR	MSE	NAE	SNR
Disk filter	22.15143	238.4251	0.094306	18.94366
Gaussian Filter	24.70774	235.2112	0.068338	21.56119
Motion Filter	23.54255	236.438	0.079097	20.37135
Average Filter	22.78	237.5502	0.087207	19.58786
Adaptive Wiener Filter	25.75787	235.7682	0.06312	22.59866
Adaptive Median Filter	25.31835	233.5066	0.058548	22.21342

Table 2. Average performance metrics for liquid based cytologic Pap Smear images

Name of the Filter	PSNR	MSE	NAE	SNR
Disk filter	23.84769	255	0.062968	21.86438
Gaussian Filter	25.78835	254.9969	0.051135	23.82351
Motion Filter	24.75702	254.9977	0.056904	22.78397
Average Filter	24.21975	255	0.06061	22.24099
Adaptive Wiener Filter	26.56161	254.9973	0.049608	24.59059
Adaptive Median Filter	25.58008	254.9872	0.047727	23.68033

4. Conclusion

Poisson noise is due to non-uniform distribution of varying photon noises, this is effectively removed using adaptive Wiener filter. Adaptive Wiener filter is independent of varying characteristics of image. It can denoise images effectively even though characteristics of image varies at different locations which is one of prime nature of Poisson noise. Adaptive Median filter which is suitable for salt n pepper noise was considered in study to find whether it is applicable for Poisson noise in Pap Smear image and found that was not providing any remarkable denoising results.

Most of the time, Pap Smear image will be captured using CCD camera at microscope eye piece. Poisson noise as discussed is more likely in these case. Motion filter approximates the values from camera, so it was considered for the study. But motion filter removed camera induced Poisson noise in moving pictures, but images in our study are still pictures and found not suitable for input images considered. Hence, from this study, it is evident that adaptive Wiener filter can be used to reduce Poisson noise in both LBC and CBC PaP Smear Microscopic image.

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