An Improved 2-D Median Filter for Impulse Noise Suppression in Television

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ABSTRACT

Nowadays, the broadcast television signal is frequently contaminated by impulse noise and produces the snowy images which are uncomfortable for spectator to view on it. One of the common filters for suppressing this type of noise is the median filter. Median filter is popular because of its noise reduction and edge preservation characteristics. Somehow, median filter is not a perfect filter. This filter has some weaknesses that are needed to be overcome. A new modified median filter is proposed in this project to solve the weaknesses of the standard median filter. This new proposed filter is implemented using Matlab. Besides, a user-friendly graphical user interface (GUI) of this proposed filter has been designed to make the user feel comfortable to handle the image noise filtering process. The experimental results of this project are good enough to prove that the proposed filter is efficient in reducing the noise filtering process time by minimizing the number of replacements. This proposed filter also good in edge preservation and impulse noise suppression.

ABSTRAK

Pada masa kini, isyarat penyiaran televisyen selalunya dicemari oleh hingar dedenyut yang menghasilkan imej bersalji. Keadaan ini tidak akan menyelesakan hati penonton yang menontonnya. Salah satu penapis tindas hingar umum ialah penapis median. Penapis median adalah popular dengan ciri-cirinya yang bertindak sebagai pengurang hingar dan pengawet pinggir. Tetapi, penapis median bukannya penapis yang sempurna, terdapat juga kelemahan yang perlu diatasi. Satu penapis median yang telah diubahsuai telah dicadangkan dalam projek ini bagi mengatasi kelemahan penapis median. Penapis yang dicadangkan ini diimplementasi dengan menggunakan pengaturcaraan Matlab. Selain itu, satu antaramuka grafik pengguna (GUI) bagi penapis cadangan yang mesra pengguna telah direkabentuk untuk memudahkan pengguna yang menjalankan proses penapisan hingar imej. Keputusan-keputusan eksperimen projek ini merupakan fakta yang boleh membuktikan bahawa penapis yang dicadangkan ini dapat menggurangkan masa proses penapisan hingar dengan meminimumkan bilangan penggantian secara efisien. Penapis ini juga bertindak baik dalam pengawetan pinggir dan penindasan hingar dedenyut.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1   Background

Around the world, there are many sources that produce unwanted noise. Noise is undesired information that contaminates an image. Commonly we can categorized them into natural and artificial noise. Artificial noise arises mainly from electrical equipments such as motor machines, sparking plugs in ignition system, electrical shaver and washing machine. Natural noise is comprises of raining and lightning, the full crowded electromagnetic waves atmosphere in this information technology world also is a huge natural noise source. The artificial and natural noises have created great deal of noise to influence the quality of our television images by causing snow effect in the images. Therefore, an image filter has to be used to filter out the noises from the snowy images. Actually, noise filtering is one branch of the digital image processing. One of the popular noise filter used for filter out the noises like impulse noise (salt & pepper noise) in images is median filter. Commonly, this median filter has two general setbacks including blocking effect on filtered images and it needs a lot of noise filtering process time for pixel replacements. Thus, in this project, an improved 2-D median filter for impulse noise suppression in television will be designed to overcome the setbacks of the original median filter and this filtering process will be done on grey scale digital images.

1.2   Project Objectives

- Design an improved 2-D median filter that can minimize filtering process time.
- Preserve the fine details and sharp edges in the image. The improved 2-D median filter must be able to eliminate the blocking effect on image after noise filtering process.
- Reduce the impulse noises in the contaminated image.

Due to the contamination of unwanted noise on images and degradation on image appearance quality, noise filtering process is essential to improve the appearance of the contaminated image and restore the original image. This is also the main objective to design a noise removing filter that is improved 2-D median filter to suppress the impulse noise which is a common type of noise will greatly affect appearance quality on satellite television or standard broadcast television images. Normally, this impulsive noise is induced through atmospheric disturbances like strong electromagnetic fields or transmission errors and so on. Besides, filter out the impulsive noise from the images, enhancement on the appearance of the images also will be concerned in the project.

1.3   Methodology of the Project

i. Input Test images:

Grey scale image is the standard image as a testing object for this project. Grey scale images [1] are referred as monochrome images. This grey scale image contains 8 bits/pixel data, which allow having 256 (0-255) different brightness levels of the images. The pixel value 0 corresponds to black and 255 to white.

ii. Noise Types:

Impulse noise (salt & pepper noise) [2] will be used to contaminate the test images in this project. The impulse noise commonly referred as intensity spikes also called binary noise because the contaminated pixels are either set to the maximum grey level value 255(white colour dot) or minimum grey level 0 (black colour dot) causing a snowy image. Generally this type of noise will only affect a small number of image pixels.

iii. Design filter:

An improved 2-D median filter which can efficiently remove the impulse noise (salt & pepper noise) from the noisy images will be designed.

iv. Implementation:

In this project, we use Matlab to design improved median filter as a noise removal filter. Matlab [3] provides a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization and algorithm development. We can restore noisy or degraded images, enhance images for improved intelligibility, extract features, analyze shapes and textures. This will allow us inspect the algorithms, modify the source code and create your own custom functions.

v. Testing and Evaluation:

After finish designed the improved median filter, the testing and evaluation on the performance of improved median filter in removing impulse noise (salt & pepper noise) from contaminated images will be executed and compare the performance with the original median filtered images will be conducted.

vi. Further Development of the Filter:

After evaluation test and ensure the improved median filter meet all the specification and objectives of the project, a user-friendly graphical user interface (GUI) for the improved median filter program will be designed to let the user handles the noise filtering process in comfortable way.

1.4   Introduction to Digital Image

An image [2] is defined as a two-dimensional function, f(x, y), where x and y are spatial (plane) coordinates and the amplitude of f at any pair of coordinates (x, y) is called the intensity of the image at that point. When x, y, and the amplitude values of f are all finite, discrete quantities, we call this image a digital image.

Simply speaking a digital image is composed of a set of pixels (picture elements) arranged according to a 2-D array. The image is divided in columns and rows, the intersection between a row and a column form a pixel (spatial). Each pixel represents the brightness of the image. The numbers of pixels in a given area determine the resolution of a digital image.
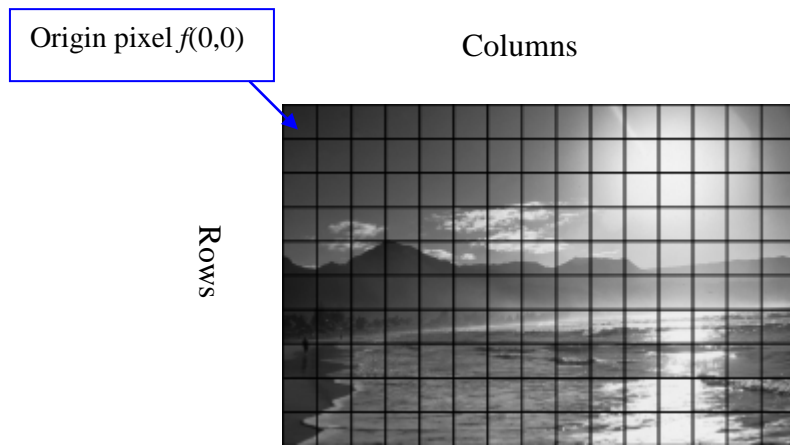
Figure 1.1: Digital Image Representation

An image f(x, y) is divided in N columns and M rows assigned to coordinates (m , n) with {m = 0,1,2,...,M-1} and {n = 0,1,2,...,N-1} which shown as **Figure 1.1**.

1.5   Introduction to Grey Scale Image

Grey scale digital images [1] are known as monochrome images. This grey scale images contain brightness information only and the displayed images are typically composed of shades of grey varying from black at the weakest intensity (0) to white at the strongest intensity (255). The number of bits used for each pixel determines the number of different brightness levels available. Grey scale images intended for visual display are typically stored with 8 bits per sampled pixel, which allows 256 (0-255) different brightness grey levels.

The accuracy provided by this 8 bits/pixel format is barely sufficient to avoid visible banding artifacts, but very convenient for programming. Technical uses in medical imaging or remote sensing applications often require more levels to make full use of the sensor accuracy (typically 10 or 12 bits per sample) and to guard against round off errors in computations [4].

1.6   Introduction to Image processing

In the broadest sense, image processing [5] includes any form of information processing in which the input is an image. Many image processing techniques derive from the application of signal processing techniques to the domain of 2-D images like photographs or video. Generally, image processing is to improve the appearance of the images through the enhancement and restoration of the images.

Why Image Processing?

- Restoring the degraded image to the original appearance
- Adjust the contrast and brightness of the images
- Removing blurring and noise on the images by the filtering process
- Image compression by reducing the typically massive amount of data needed to represent the data
- Geometric transformations such as image enlargement, reduction and rotation
- Segmentation of the image into regions
- Combination of two or more images like image composite

1.7   History of Digital Image Processing

The history of image processing [2] started when the first powerful computers invented in the early 1960s. The inventions of the computer bring the developments and generate potential of digital image processing concepts.

The first computer aided image processing method for improving images began from a space probe at the Jet Propulsion Laboratory (Pasadena, California) in 1964 when pictures of the moon transmitted by *Ranger 7* were processed by a computer to rectify various types of image distortion inherent in the on-board television camera. The imaging lessons learned with *Ranger 7* served as the basis for improved methods used to enhance and restore images from the Surveyor missions to the moon, the Mariner series of flyby missions to Mars, the Apollo manned flights to the moon and others.

The first picture of the moon by a U.S. space craft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)
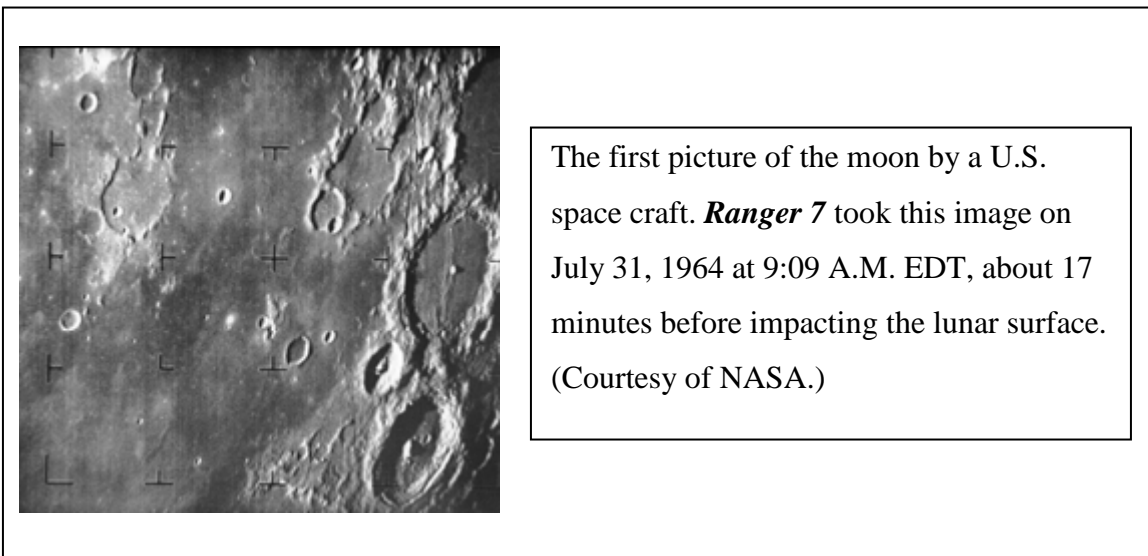
Figure 1.2: Moon

In the early 1970s, digital image processing techniques began to be used in medical imaging, the invention of computerized axial tomography (CAT) also called computerized tomography (CT) and this is one of the most important events in the application of image processing in medical diagnosis. Computerized axial tomography is a process in which a ring of detectors encircles an object (or patient) and X-ray sources, concentric with the detector ring, rotating the object. In this modern age, digital image processing techniques are used in a broad range of applications. Computer image processing techniques are used to adjust the contrast or code the intensity levels into colour for easier interpretation of X-rays and other images used in industry, medicine and the biological sciences. In archaeology, image processing techniques have successfully restored blurred images that were the only available records of rare artefact lost or damaged after being photographed. Geographers use image processing techniques to study pollution patterns from aerial and satellite imagery. Image enhancement and restoration procedures are used to process degraded images which is difficult to execute it in practical lab and indirectly reduce the research expenses. In physics fields, image processing techniques usually used to enhance images of experiments in areas such as high-energy plasmas and electron microscopy.

With the fast development of computers and signal processors in the 2000s, digital image processing has become the most common form of enhancing and improving the appearance of the image. The continuing improvement of the computer and the expansion of networking and communication bandwidth via the WIFI and the internet have produced infinite opportunities for continuing growth of digital image processing.

1.8   Introduction to Television

There are two television display systems in commercial use there are PAL and NTSC. PAL (common in Europe and parts of Asia) delivers a scanning frame rate of 25 frames per second, while NTSC (used in the U.S. and Canada) delivers a scanning frame rate of 29.97 frames per second. In Malaysia, our television is using PAL format which has 25 frames per second and 50Hz refresh rate.

1.8.1   The PAL & NTSC Standards Review

PAL (Phase Alternate Line)

A 625 line 50 interlaced fields per second analogue broadcast standard used in many parts of the world but not the U.S.A. It is named this way because the chrome is phase reversed on every other scan line to reduce picture artifacts. The PAL active picture is contained in about 52 µs of 576 active scan lines.

NTSC (National Television System Committee)

U.S. government and industry committee defined the 525 line 60 interlaced fields per second for standard NTSC analogue broadcast TV. The active NTSC [6] picture is contained in about 52.6555 µs of about 480 active scan lines.

1.8.2 TV resolution

TV resolution [7] can be described as number of lines per mm or inch in both vertically and horizontally. Normally, TVs resolutions are specified by both horizontal resolution and vertical resolution. Horizontal resolution is measured by how many vertical lines can be seen at one time across the screen. Vertical resolution is measured by how many horizontal lines can be seen at one time up and down the screen. Modern standards stating resolution or screen dimensions in "pixels" (dots) reflect the entire screen width or height.

TV Resolution = Horizontal resolution ×Vertical resolution

For example:

720×480 = 345600 pixels

768×576 = 442368 pixels

1.8.3 Frame rate/Aspect Ratio

Television signals provide a slideshow of images fast enough to make our eye into believing we are seeing real motion. Film uses 24 frames and standard television (PAL) uses 25 frames per second which has a 50Hz refresh rates, while NTSC uses 30 frames per second which has 60Hz refresh rates [8]. By now for the high definition TV, its can produces up to 100Hz refresh rate and 50 frames per second.

Our televisions sizes have a standard 4:3 and 16:9 aspect ratios [8]. That means the width of the picture is $1\frac{1}{3}$ times the height. Horizontal resolution is referenced to picture height, i.e., $\frac{3}{4}$ of the picture width. For example, if your TV has 300 lines of horizontal resolution per picture height it will have a total of $1\frac{1}{3} \times 300$ or 400 lines across the entire width of the picture.

Table 1.1: Standard TV Specification

TV Format	Vertical Resolution	Horizontal Resolution	Aspect Ratio (The Display's Width & Height Ratio)	Display Rate (Frames/s)
NTSC	480	720	16:9 or 4:3	30
PAL	576	768	16:9 or 4:3	25

By referring to the specification of the standard PAL TV the frames rate is 25 frames per second, in the other word its mean that there are 25 images or frames appear on the screen in 1 second. This frame rate is considered very fast to us to process and filtering the images in such tense conditions. Thus, filtering time play an important role in designing the improved median filter for this project.

CHAPTER 2

NOISE AND NOISE REDUCING FILTERS

2.1   Noise

Noise is any unwanted signal that contaminates an image by adding a random value to the original given pixel value. There are two types of common noises contaminate the images i.e. Gaussian noise and impulse noise (salt and pepper noise). Impulse noise (salt & pepper noise) [2] is origin from errors in data transmission. Gaussian noise [2] is a random interference generated by the movement of electricity in the cable line, the thermal vibrations of atoms in antennas, radiation from the earth and other warm objects like sun.

2.1.1   Gaussian noise

Gaussian noise [2] is also called as "white noise". In Gaussian noise the noise is uniformly distributed and this noise will be added to every part of the picture. Each pixel in the image will be changed from its original pixel value by a small amount. By plotting the amount of distortion of a pixel value against the frequency with which it occurs produces a Gaussian distribution (normal distribution) and is often described as a "bell-shaped curve" as shown in **Figure 2.1**.

Gaussian noise is a really good approximation of noise that occurs in many practical cases. With the uniform distribution, the grey level values of the noise are distributed in a specific range which the grey level values start from 0 to 255 in 8 bits/pixel data [2].

The probability density of the random variable is given by $P(z) = \dfrac{1}{\sqrt{2\pi}\sigma}e^{\frac{-(z-\mu)^2}{2\sigma^2}}$,

z= grey level;

μ = mean of value z;

σ = standard deviation;

σ^2 = variance of z

$$P(z) = \frac{1}{\sqrt{2\pi}\sigma}e^{\frac{-(z-\mu)^2}{2\sigma^2}}$$
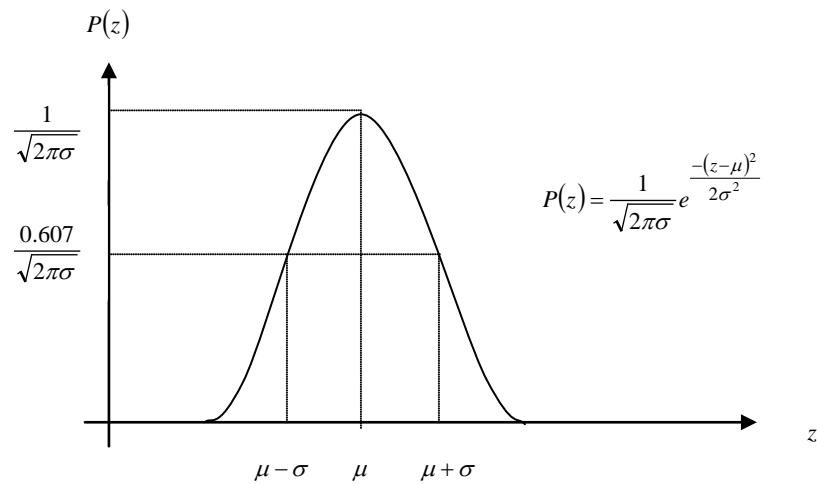
Figure 2.1: Gaussian Distribution

| Original image | Gaussian noise contaminated image |
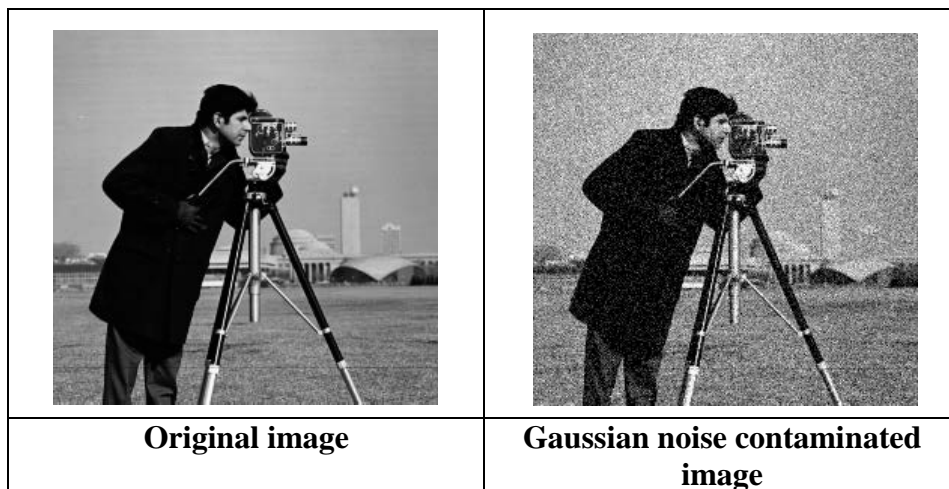
Figure 2.2: The Gaussian Noise impairment on grey scale image

2.1.2 Impulse Noise (Salt and Pepper Noise)

Impulse noise (salt and pepper noise) [2] commonly referred as intensity spikes. Impulse noise is caused by errors in data transmission and it also called as binary noise because the contaminated pixels are either set to the maximum grey level value 255 (white colour dot) or minimum grey level 0 (black colour dot) causing a snowy image. Generally this type of noise will only affecting a small part of the whole image pixels.
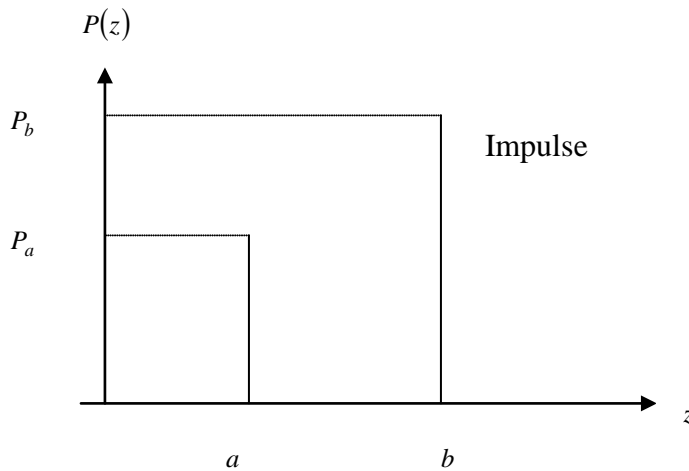
Figure 2.3: Probability Density Function of Impulse Noise

$$P(Z)=\begin{cases} P_a & for\ z=a \\ P_b & for\ z=b \\ 0 & otherwise \end{cases}$$

For a>b, grey level a will represent a black dot in the image.
For b>a, grey level b will represent a white dot in the image.

If P_a or P_b is zero, the impulse noise is called unipolar. If $P_a = 0$, then this is salt noise; else if $P_b = 0$, then this is pepper noise [2].

If P_a and P_b not zero, then this will produce bipolar noise or salt and pepper noise [2].

| Original image | Salt and pepper noise contaminated image |
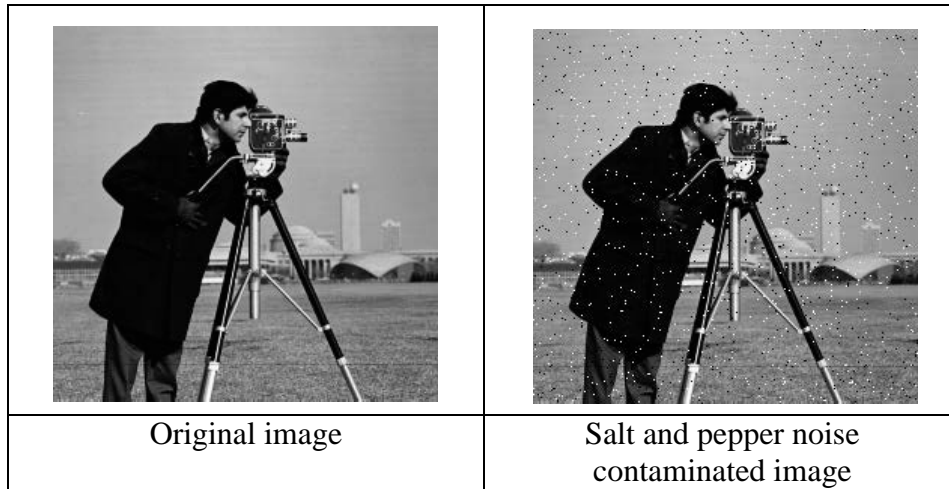
Figure 2.4: The Salt and Pepper Noise impairment on grey scale image

2.2 Different Noise Reducing Filters/Techniques Used in Image Processing

In this section, we will study on the characteristics and filtering methodology of mean filter, order filters like maximum, minimum and median filter. Besides, we will also compare the performance of different types of filters which mention above.

2.2.1 Mean Filter

Mean filter is a simple smoothing images tool; it can be used to reduce noises in images by reducing the amount of intensity variation between the consideration pixel and the neighbourhood's pixels. Mean filter is based around a filter window (sub image), which represents the shape and size of the neighbourhoods to be sampled for calculating the mean [9]. The mean filter works by replacing each pixel value in an image with the average value of neighbourhood's pixels in the define filter window size (the sum of pixels values of the neighbourhoods divided by total sub image window pixels is equal to average value) [9].

The mean filter is applying the window sliding concept. The filter window is starts laid on upper left corner like the **Figure 2.5**. After determine the mean value, the average pixel value will be substituted to the centre location of the filter window, filter window is

then slide one pixel to the right and this process will be repeated. When the end of the row is reached, the window will slide back to left hand side of the image and down one row and this process is repeated. This sliding process will be continuing until the whole image has been processed [1]. Note, for 3×3 filter window the outer rows and columns pixels are not replaced. In practically, this is accepted due to the fact that images are much larger than the window size, usually these rows and columns are filled with zeros. These zero pixels value will produce a black frame on the noise filtered image. Then, for 5×5 filter window there are two outer columns and rows filled with zero pixel value and there are three outer columns and rows zeros for 7×7 filter window.
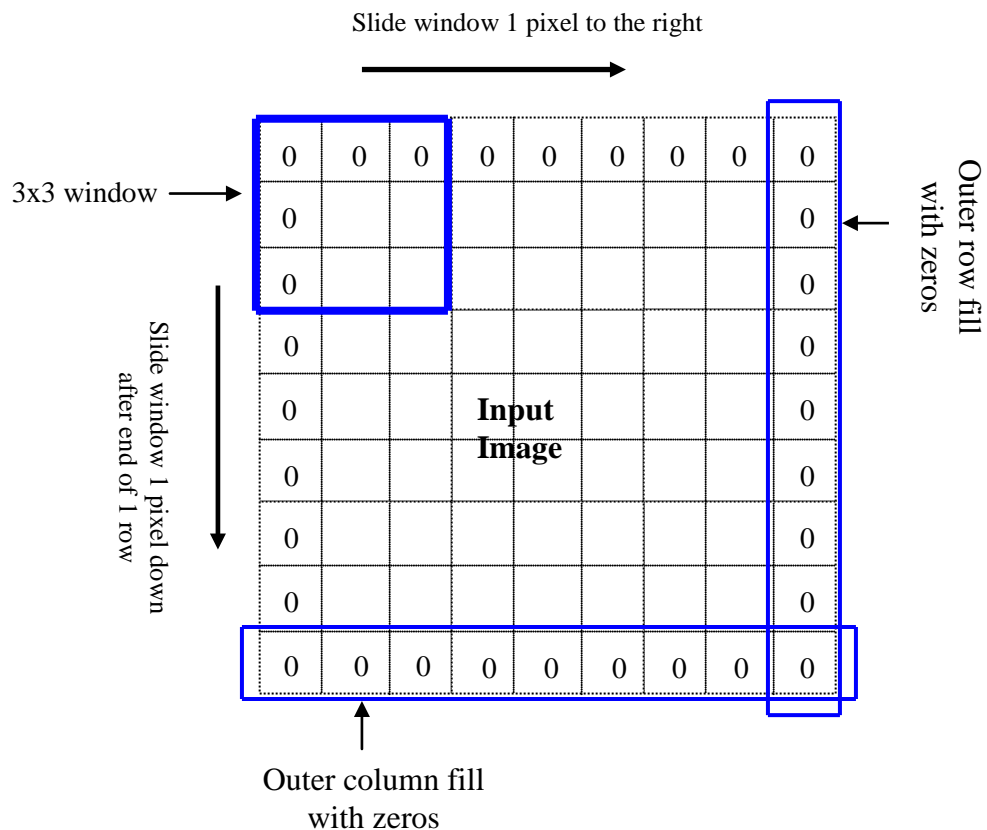
Figure 2.5: Example of 3×3 window sliding

Mean Filter Equation Representation

Let S_{xy} represent a set of coordinates in a rectangular sub image window of size m×n, centred point (x,y). The mean filter computes the average value of the corrupted image g(x,y) in the area defined by S_{xy}.

n columns →

m rows ↓

(x-1,y-1)	(x,y-1)	(x+1,y-1)
(x-1,y)	(x,y)	(x+1,y)
(x-1,y+1)	(x,y+1)	(x+1,y+1)
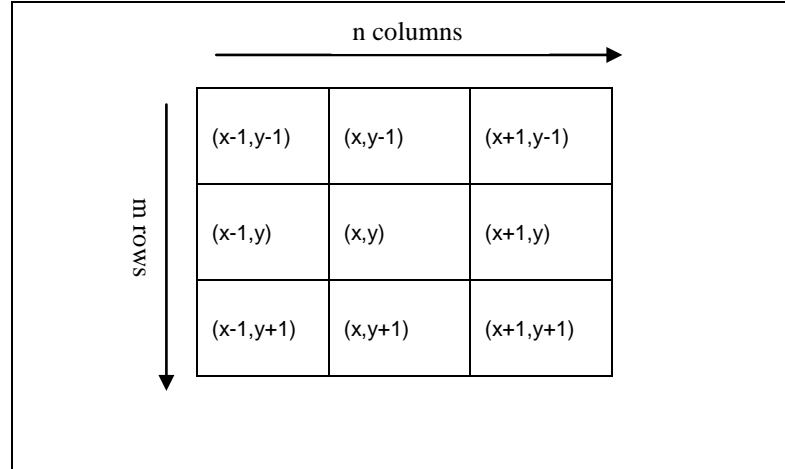
Figure 2.6: Example of 3×3 filter window represented by Sxy

The value of restored image $\hat{f}$ at any point (x,y) given by this equation [2]:

$$\hat{f}(x,y) = \frac{1}{mn} \sum_{(s,t) \in S_{xy}} g(s,t)$$

mn = sub image window size

$\sum_{(s,t) \in S_{xy}} g(s,t)$ = Total noise corrupted pixels values in the m×n sub image window

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Example for Mean Filtering Calculation

For enhance understanding of mean filter working process, we look at the below mean filter calculation example.

Slide window 1 pixel to the right

23	88	57	43	46	99	78
56	21	32	44	56	66	63
58	36	123	156	133	25	77
125	41	77	89	12	33	56
33	14	55	16	122	33	124
45	23	32	21	145	166	145
28	200	99	101	36	131	120
2	212	104	102	78	87	15

Slide window 1 pixel down after end of 1 row
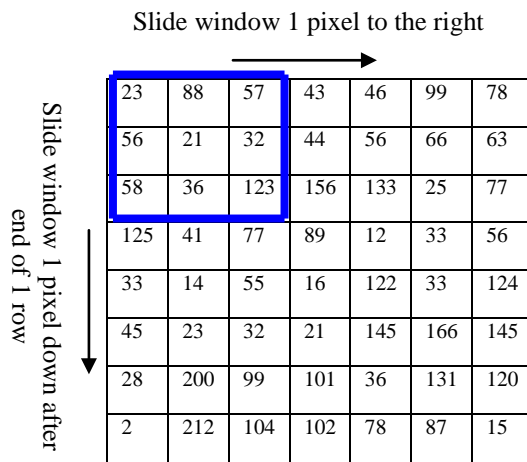
Figure 2.7: Example of Impulse Noise Contaminated Image Pixels

The filter window size using in this example is m×n = 9

Now, consider the first 3×3 window as below:

23	88	57
56	21	32
58	36	123

$$\sum_{(s,t)\in S_{xy}} g(s,t) = \{23+88+57+56+21+32+58+36+123\}$$

$$= 494$$

$$\hat{f}(x,y) = \frac{1}{mn}\sum_{(s,t)\in S_{xy}} g(s,t)$$

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Thus, centre pixel in the 3×3 filter window will be replaced by average pixel value, $\hat{f} = \dfrac{494}{9}$ after mean filtering.

The first 3×3 window centre pixel value after mean filtering is shown as below:

	$\dfrac{494}{9}$	

Now, we are increasing the filter window size to 5×5.

For 5×5 window calculations are as below:

23	88	57	43	46
56	21	32	44	56
58	36	123	156	133
125	41	77	89	12
33	14	55	16	122

Filter window size, m×n = 25

$$\sum_{(s,t)\in S_{xy}} g(s,t) = \{23+88+57+43+46+56+21+32+44+56+58+36+123+156+133+$$

$$125+41+77+89+12+33+14+55+16+122\}$$

$$= 1556$$

$$\hat{f}(x,y) = \frac{1}{mn}\sum_{(s,t)\in S_{xy}} g(s,t)$$

Thus, centre pixel in the 5×5 filter window will be replaced by average pixel value, $\hat{f} = \frac{1556}{25}$ after mean filtering.

The first 5×5 window centre pixel value after mean filtering is shown as below:

		$\frac{1556}{25}$		

Performance Comparison between 3×3 and 5×5 Size Filter Window

By comparing the 3×3 and 5×5 size window calculation examples, we can see that when apply bigger size filter window (5×5 window), we were consider more or larger samples pixels values. As the size of the window increased the image began to blur or smooth more over problem arise because the edges between pixels values began to merge together due to the similar pixels values or same brightness values around the bigger neighbourhoods which will gave the look of a more blurry image for the bigger size filter window image.

In the same time, when apply bigger size window the noise can be removed better than using smaller sub image window size. The reason is the noises in the bigger sub image are equally divided to more pixels samples. So the noises intensity is spread to every pixel in the bigger samples filter window and each of the pixels has received low noises intensity. Consequently, after using bigger size filter the noises contaminated image is looks less noises contaminated but looks blurry.

Original image	Impulse noise contaminated image
After 3×3 mean filtering	After 5×5 mean filtering
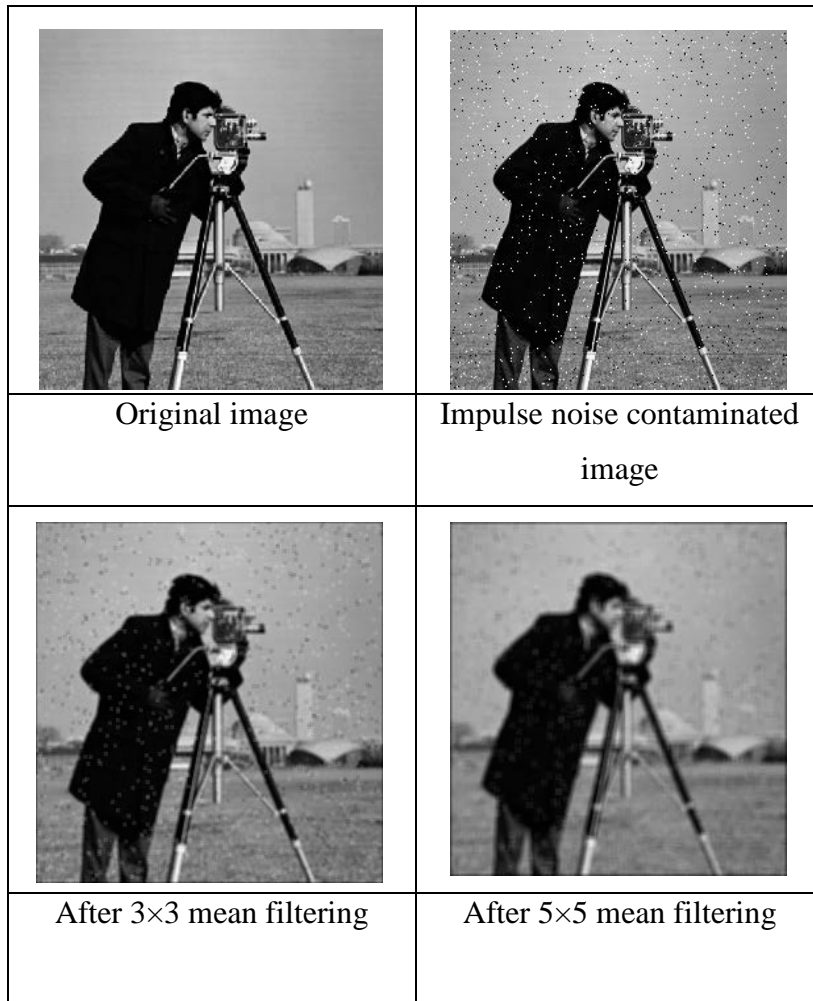
Figure 2.8: Mean Filtered Images

The performance of removing the noise from the image is proportional to filter window size. The bigger the window size the more efficient the mean filter removing the noise i.e. the 5×5 mean filter is work better than 3×3 mean filter. In conclusion, if we increase the size of the mean filter window, we will obtain an image with less noise but less fine detail causing blurry image, the mean filtering result is shown in **Figure 2.8**.

Disadvantages of mean filter

- When the filter window size of the mean filter is increased, this will allow us remove the noise better but in the same time we also loss fine details of the image. The image becomes blurred when we using the bigger filter window size.
- Mean filter loss its fine image detail by replacing the average value in the filter window. When the mean filter neighbourhood straddles an edge, the filter will interpolate new values for each pixel on the edge and so will merge those edges.
- Mean filter main effect is to distribute the intensity of the impulse noise spikes among the surrounding pixels, making the noisy pixels slightly less noticeable, but not eliminating them. For images containing a substantial amount of noise, the filtered image sometimes appears worst than the original. This effect is compounded by the fact that pixel averaging blurs the image, resulting in a significant loss of fine image detail. In addition, brightness differences across boundaries are reduced by pixel averaging.

2.2.2 Order Filters

There are 3 types of difference filters in order filters as mention below:

- **Minimum filter**
- **Maximum filter**
- **Median filter**

Generally, these order filters [1] operate on a specified window size, sorting all the pixels values of defined window in ascending order and then replace the original centre window pixel value by the min, max or median value of the window depend on the types of filter we are used.

2.2.2.1 Minimum filter

This filter works by replacing the value of the centre window pixel by the smallest value of neighbouring pixels covered by an n×m window. This filter is useful to find the darkest points in the image [2], it working well for high value type of salt and pepper noise. If applied to a binary label field the minimum filter implements erosion operation. It reduces the size of a segmented region by removing pixels from its boundary [10].


| Original image | Salt & pepper noise contaminated image | Minimum filtered image |
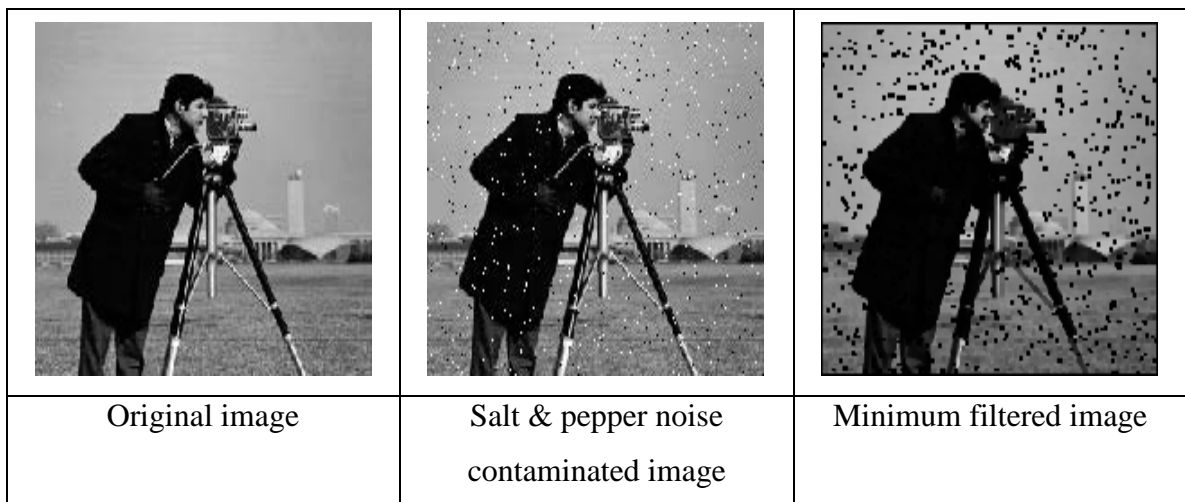
Figure 2.9: Minimum Filtered Image

2.2.2.2 Maximum filter

      This filter works by replacing the value of the centre window pixel by the largest value of neighbouring pixels covered by an n×m window. This filter is useful to find the brightest points in the image [2], it working well for low value type of salt and pepper noise. If applied to a binary label field the maximum filter implements dilation operation. It enlarges the size of a segmented region by adding pixels to its boundary [10].

| Original image | Salt & pepper noise contaminated image | Maximum filtered image |
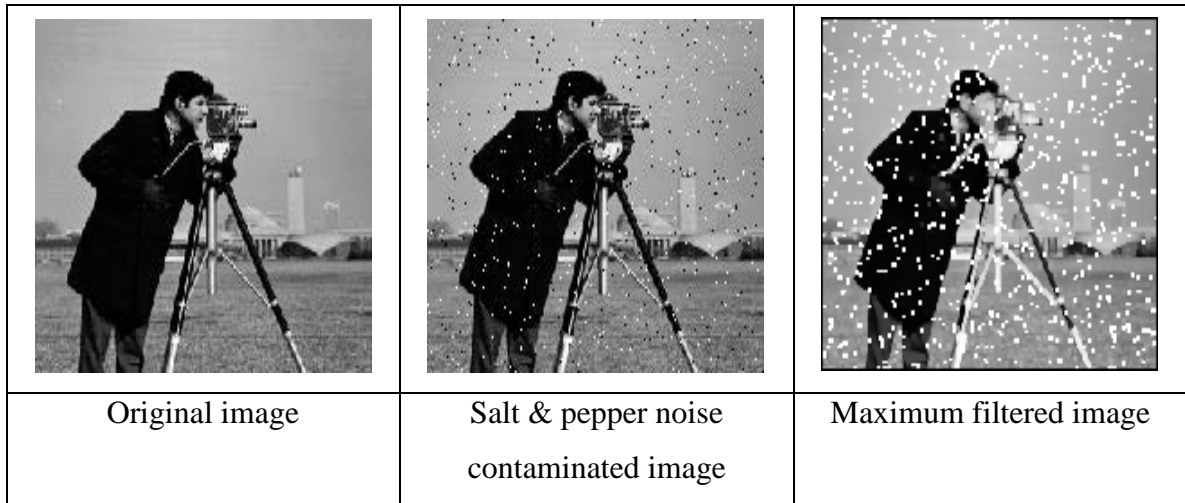
Figure 2.10: Maximum Filtered Image
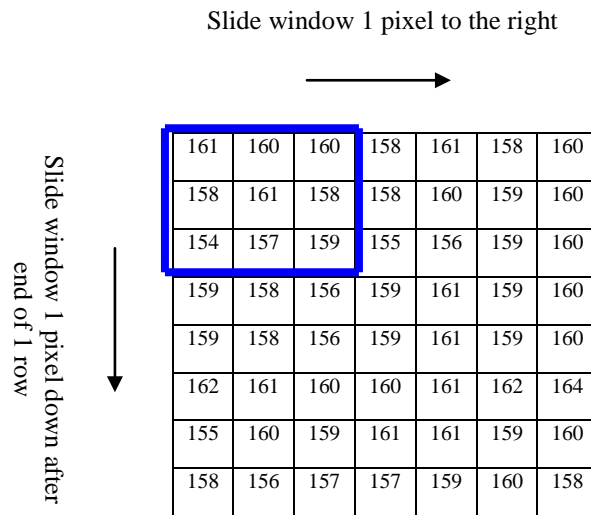
2.2.2.3 Median Filter

      In median filter, the median value is calculated by first sorting all the pixel values from the surrounding neighbourhood in ascending order and then replacing the centre window pixel with the middle pixel value of the sorted neighbourhood's pixels [11]. If the neighbourhood under consideration contains an even number of pixels, the average of the two middle pixel values is used [12].

      The median filter is applying the window sliding concept same like mean filter. The window of the filter is starts laid on upper left corner like the **Figure 2.11**. After determine the median value and replace this value to centre location of the window, window is then slide one pixel to the right and this process will be repeated. When the end of the row is reached, the window will slide back to left hand side of the image and down one row and this process is continued. This sliding process will be continuing until the whole image has

been processed. Note, for 3×3 window the outer rows and columns pixels are not replaced, in practically this is accepted due to the fact that images are much more larger than the window size, usually these rows and columns are filled with zeros [1] same as mean filter.

Example for Median Filtering Calculation

For enhance understanding of median filter working process, we look at the below median filter calculation example.

Slide window 1 pixel to the right

161	160	160	158	161	158	160
158	161	158	158	160	159	160
154	157	159	155	156	159	160
159	158	156	159	161	159	160
159	158	156	159	161	159	160
162	161	160	160	161	162	164
155	160	159	161	161	159	160
158	156	157	157	159	160	158

Slide window 1 pixel down after end of 1 row

Figure 2.11: Example of Impulse Noise Contaminated Image Pixels