Template for PhD Thesis

A thesis
submitted in fulfillment of the requirements
for the award of the degree of

Doctor of Philosophy

submitted by

R. V.
(Reg. no. ....)

Under the Supervision of

Prof. R. P.

Department of Electronics & Communication Engineering
National Institute of Technology Kurukshetra
Kurukshetra, Haryana, India-136119

(August, 2018)

Department of Electronics & Communication Engineering
National Institute of Technology Kurukshetra
Haryana, India-136119

Candidate's Declaration

I hereby declare that the work presented in the thesis entitled **"Thesis Title"** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** and submitted in the Department of Electronics and Communication Engineering of the National Institute of Technology Kurukshetra is an authentic record of my own work carried out during a period from March 2013 to August 2018 under the supervision of **Prof. R. P.**, Department of Electronics and Communication Engineering, National Institute of Technology Kurukshetra.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute/University.

(R. V.)
(Reg. no. ....)

This is to certify that the above statement made by the candidate is true to the best of our knowledge and belief.

(Dr. R. P.)
Professor, ECE Department
NIT Kurukshetra

Place: Kurukshetra
Date:

Dedicated to my family

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(R. V.)

ABSTRACT

Digital images and videos are generally degraded by noise due to malfunctioning of imaging devices, transmission errors, and environmental conditions. A plethora of image denoising techniques have been studied to tackle the denoising problem in spatial-domain, transform-domain, and hybrid domain, which can also be classified as local or non-local. In past few years, non-local denoising methods such as the non-local means (NLM) and BM3D algorithms have gained much attention in image processing community.

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List of Acronyms/Abbreviations

2D	Two Dimensional
3D	Three Dimensional
ABM3D	Adaptive Block-Matching in Three Dimensions
ANLM	Adaptive Non-Local Means
ASRBS	Anisotropic Shaped Region based Bayes-Shrink
ASRWF	Anisotropic Shaped Region based Wiener Filtering
BF	Bilateral Filter
BM3D	Block Matching in Three Dimensions
CPW	Center Pixel Weight
dB	Decibel unit
DCT	Discrete Cosine Transform
DLWFDW	Doubly Local Wiener Filtering with Directional Windows
DWT	Discrete Wavelet Transform

MAP	Maximum a Posteriori
MSE	Mean Squared Error
MSSIM	Mean Structural Similarity Index Measure
NASWF	Nearly Arbitrarily Shaped Window based Wiener Filtering
NLM	Non-Local Means
NSS	Non-Local Self-Similarity

List of Symbols

η	Gaussian noise with distribution $\mathcal{N}(0, \sigma^2)$
σ	Noise level
$\hat{\sigma}$	Estimated noise level
σ_G	Standard deviation of gray level difference image $\triangle\hat{U}_G$
$\sigma^2_{\Omega_i}$	Local variance for i^{th} pixel
$\sigma^2_{\max}$	Maximum value of variance
$\sigma^2_{\min}$	Minimum value of variance
$\sigma^2_{x_i}$	Original signal variance or energy of i^{th} wavelet coefficient
$\hat{\sigma}^2_{x_i}$	Estimated signal variance or energy of i^{th} wavelet coefficient
γ	Grey relation coefficient
λ	Non-centrality parameter
μ_E	Average of entropy image E
μ_G	Average of gray level difference image $\triangle\hat{U}_G$
$\triangle\hat{U}_G$	Gray level difference image
$\|.\|$	Cardinality

$max(.)$	maximum function
N	Number of decomposition levels in wavelet domain
P_E	Percentage of edge content in the edge image
S_i	Search region centered on pixel i
$sgn(.)$	Signum function
$\mathcal{T}_{1D}$	1D Transform
$\mathcal{T}_{2D}$	2D Transform
$\mathcal{T}_{3D}$	3D Transform
T_{hard}	Hard thresholding
T_{soft}	Soft thresholding
τ_{match}	Threshold used for block matching in BM3D method
U	Clean image in spatial domain
$\hat{U}$	Estimated clean image in spatial domain
$u(i)$	Value of i^{th} pixel of clean image U

Chapter 1

Introduction

This Chapter provides a brief description of image denoising and its goals. The motivation and objectives of the present research work are presented. It also highlights the organization of the thesis.

1.1 Background

Digital images play an important role in our daily life due to rapid growth in multimedia technologies. The noise in digital images provides unpleasant effects, which may be caused by malfunctioning of camera sensors, transmission errors, faulty memory locations, timing errors in analog-to-digital converters, mechanical instabilities in image scanners, and environmental conditions like poor illumination [1, 2].

Note: ***To insert the figures in proper format, i used MS visio software. Import the matlab figures in eps format to visio software and then go to fit to drawing option in visio and save it as .pdf format.***

if you do not want to use Visio, use MATLAB 2019 or later, to save the images in cropped form. In Matlab 2019 or later, the saved images are already in cropped form in eps format. No extra white space will come.

Image denoising is basically an estimation process to reconstruct the original image from the noisy observations, while preserving the important non-linearities present in

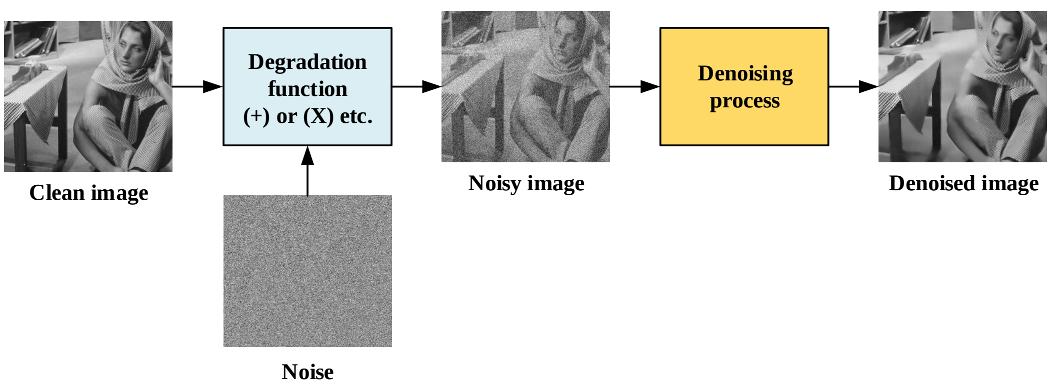

Figure 1.1: Image degradation due to noise, and denoising model

an image. Usually, there is a trade-off between noise suppression and the preservation of key image details. Therefore, image denoising remains an active fundamental research problem, which has attracted researchers to perform better denoising in the presence of high noise [3].

1.2 Motivation for the present research work

Image denoising is a preprocessing task in high level image processing applications to extract some useful information or key features. An extensive literature of linear and non-linear image denoising algorithms reveals how an image denoising problem can be solved in spatial domain [4], transform domain [5], and hybrid domain [6], but there is still room available for improving the performance of denoising algorithms and overcoming their limitations. The main goals of image denoising are described below:

- The homogeneous or flat regions in an image should be as smooth as possible.
- Important image details such as edges, textures and corners should be well preserved and they should not be blurred or sharpened.
- No artifacts such as staircase and ringing should appear in the restored image.

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1.3 Problem statement

There are several factors which may cause degradation of images. However, the present research work mainly concentrates on the removal of Gaussian noise from digital images .... algorithms. To improve their performance, the relevant parameters are adaptively selected on the basis of natural properties of local regions in the images. The objectives of the thesis are summarized as follows:

i) To study the existing image denoising techniques available in the literature and identify the critical issues influencing their performance.

ii) To develop an algorithm to change the smoothing parameter in the NLM algorithm adaptively based on region characteristics.

1.4 Organization of the thesis

The research work presented in the thesis is organized and structured in the form of seven chapters, which are briefly described as follows:

i) **Chapter 1** ************************

ii) **Chapter 2** ....

iii) **Chapter 3** ....

iv) **Chapter 4** ....

v) **Chapter 5** ....

vi) **Chapter 6** ....

vii) **Chapter 7** concludes the thesis with overall discoveries of the present research work. The scope for future work is also mentioned.

Chapter 2

Literature review

This Chapter presents a survey of most commonly used noise models for digital image processing. ....

2.1 Section-I

Noise models............................

$$v(i) = u(i) + \eta(i) \tag{2.1.1}$$

2.1.1 Subsection-I

Gaussian noise is also known as electronic noise [7, 8].

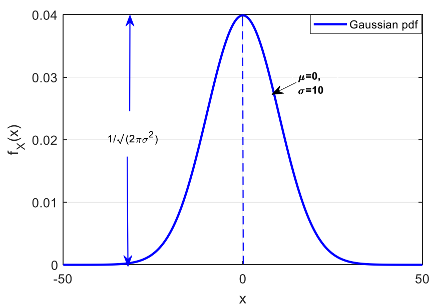

Figure 2.1: Probability density function for Gaussian noise

2.2 Review of algorithms

Image denoising techniques have been extensively studied to solve the denoising problem for Gaussian noise and vast literature is available in this area.....................

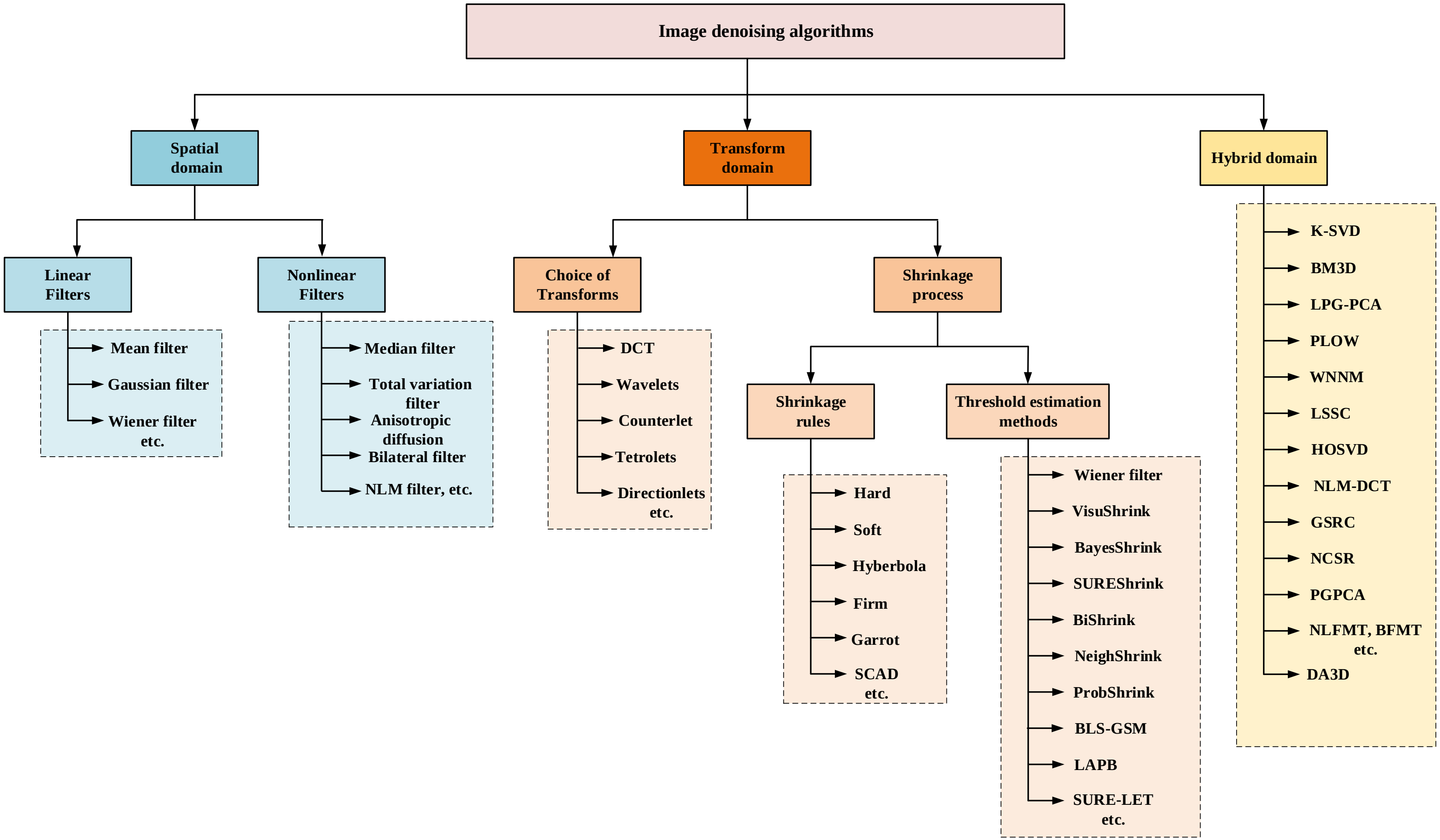

Figure 2.2: A brief overview of image denoising algorithms

2.2.1 Subsection -I

Subsubsection-I

Spatial domain linear ....

$$w(i,j) = \frac{w'(i,j)}{\sum_j w'(i,j)} \qquad \text{such that } w'(i,j) = \begin{cases} 1, & \text{if } j \in v(N_i) \\ 0, & \text{otherwise} \end{cases} \tag{2.2.1}$$

2.3 Summary

In this Chapter, a survey of various image denoising techniques in spatial, transform, and hybrid domains has been presented. Various image denoising schemes...............................

Chapter 3

Title of Chapter 3

The choice of smoothing parameter plays an important role in the denoising performance of NLM algorithm as described in Chapter 2.

3.1 Background

To preserve the inherent non-linearities of an image effectively, the weights in NLM algorithms are selected on the basis of similarity measure and smoothing parameter.............

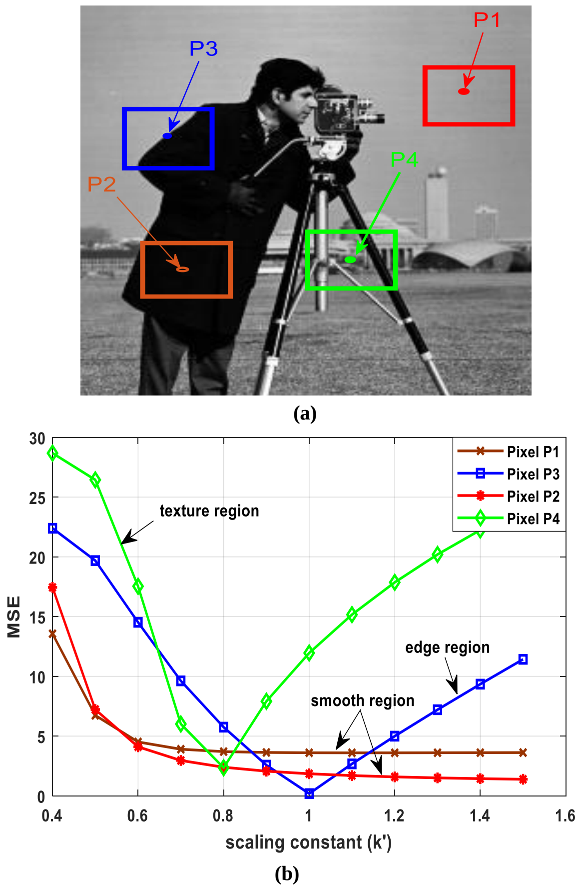

Figure 3.1: a) Illustration of various regions in an image b) Variation of MSE with respect to scaling constant k' used in smoothing parameter h for pixels lying in different regions at $\sigma = 20$

As described previously, the noisy image pixel $v(i)$ at location $i = [p_i, q_i]$ containing $i.i.d$ Gaussian noise η with distribution $\mathcal{N}(0, \sigma^2)$ is modeled as

$$v(i) = u(i) + \eta(i) \tag{3.1.1}$$

3.2 Proposed algorithm

An image contains different types of regions such as homogeneous (e.g. smooth) and non-homogeneous (e.g. edges,textures etc.) regions. ....

3.2.1 Title of subsection

Let R_i be a region of size $R \times R$ centered on a pixel i in the noisy image V. The region R_i is divided into ....

$$F = \begin{bmatrix} f_{1,1} & f_{1,2} & . & . & f_{1,n} \\ f_{2,1} & f_{2,2} & . & . & f_{2,n} \\ . & . & . & & . \\ . & . & & . & . \\ f_{m,1} & f_{m,2} & . & . & f_{m,n} \end{bmatrix} \tag{3.2.1}$$

3.3 Experimental results

This section presents quantitative and qualitative results of the proposed algorithm (GRANLM) shown in terms of peak signal to noise ratio (PSNR) in dB, visual quality and method noise [9].

3.3.1 Choice of parameters in the proposed algorithm

For calculating the ....

Table 3.1: Denoising results in terms of PSNR(dB) for several combinations of search region size and patch size at $\sigma = 20$

Search region size	**Peppers**					**Barbara**				
Patch size	3×3	5×5	7×7	9×9	11×11	3×3	5×5	7×7	9×9	11×11
9×9	.....	.....	.....	-	-	....	....	.....	-	-
11×11	.....	.....	....	....	-	....	....	....	....	-
13×13	....	....	**....**	....	....	....	....	**.....**	.....	26.5759
15×15	....	.....	.....	.....	.....	.....	.....	.....	.....	.....
17×17	....	.....	.....	29.8967	29.8892	27.7309	28.0336	27.9060	27.8226	27.7377
19×19	29.8931	29.9918	29.8429	29.9114	29.8252	27.5868	27.9062	27.8153	27.6665	27.7043
21×21	29.7556	29.8558	29.4792	29.5306	29.6600	27.5175	27.8335	27.6800	27.5971	27.5138

3.4 Summary

summary of the chapter

Chapter 4

Title of Chapter 4

In addition to the issue of global smoothing parameter in NLM algorithm as discussed in Chapter 3, the selection of search size is another critical issue that also affects the performance of NLM algorithm.

4.1 Introduction

NLM algorithm exploits the self-similarities present in the whole image or a predefined search region of fixed size [10, 11].

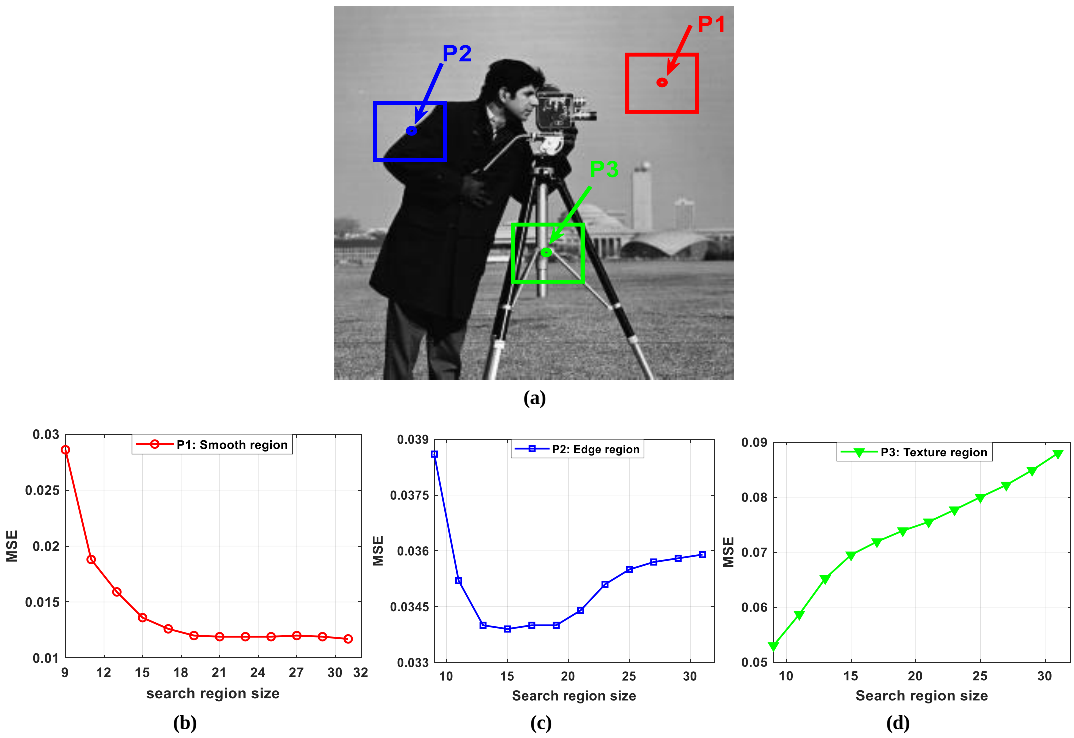

Figure 4.1: Mean square error (MSE) with respect to different search region size for standard cameraman image at $\sigma = 20$ a) Illustration of various regions b) smooth region c) edge region d) texture region

4.2 Section-I

The core idea of the proposed ....

4.3 Experimental results

In this section, ...

4.3.1 Choice of parameters in the proposed methods

....

4.4 Summary

In this chapter, ...

Chapter 5

Titile of chapter-5

The shape of a local window .... noise.

5.1 Introduction

Wavelet-based image denoising ....

5.2 Section-I

5.2.1 Subsection-I

Let $u(i)$ and $v(i)$ ....

$$v(i) = u(i) + \eta(i) \tag{5.2.1}$$

5.3 Proposed approach

The shape of the local window i....................

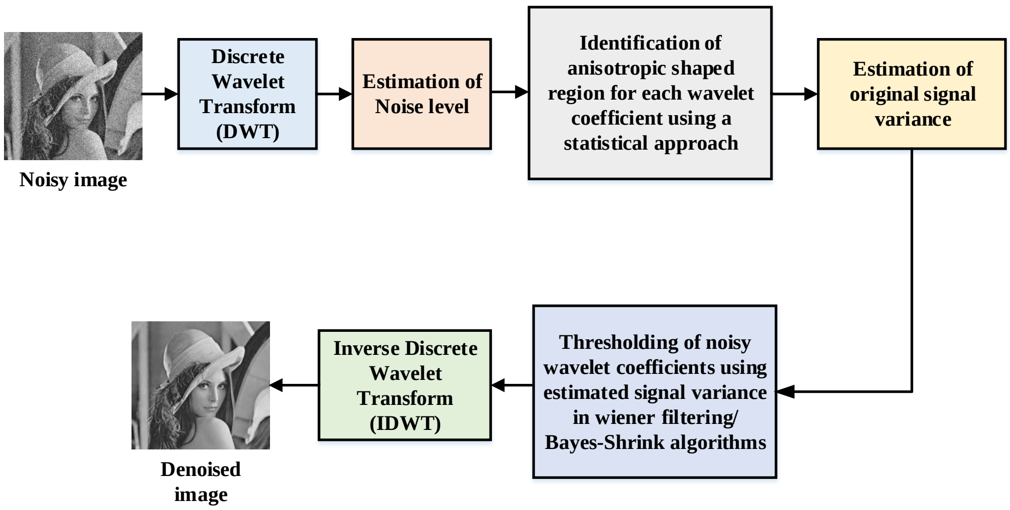

Figure 5.1: Block diagram of the proposed approach

5.3.1 Subsection

Let R_i be a ......

5.4 Experimental results

In this section, ...

5.4.1 Choice of parameters in the proposed approach

For all experiments, ...

5.5 Summary

In this chapter, ...

Chapter 6

Chapter-6 title

This Chapter explores the ....

6.1 Introduction

Generally, non-local methods ....

6.2 Fusion of spatial and wavelet-based methods

The performance of NLM .... In order to highlight the limitations of non-local and wavelet-based methods, the denoised results obtained by using NLM [11], Bayes-Shrink [12], and Neigh-Shrink [13] algorithms at $\sigma = 30$ for standard Baboon image are presented in Fig. 6.1.

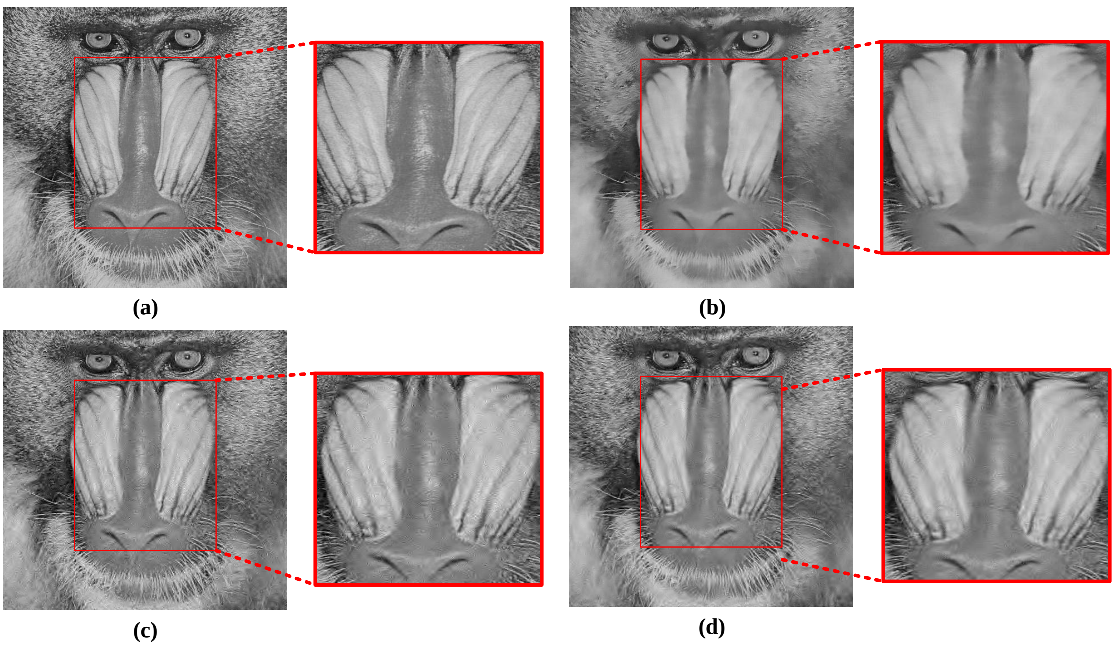

Figure 6.1: Denoised Baboon image using various denoising methods at $\sigma = 30$ a) clean b) NLM c) Bayes-Shrink d) Neigh-Shrink with corresponding zoomed regions

6.3 Adaptive BM3D algorithm

6.3.1 Conventional BM3D algorithm

Block-matching in three-dimensions (BM3D) method ....BM3D algorithm is basically a two-stage method as shown in Fig. 6.2, where each stage mainly consists of three steps named as grouping, collaborative filtering, and aggregation.

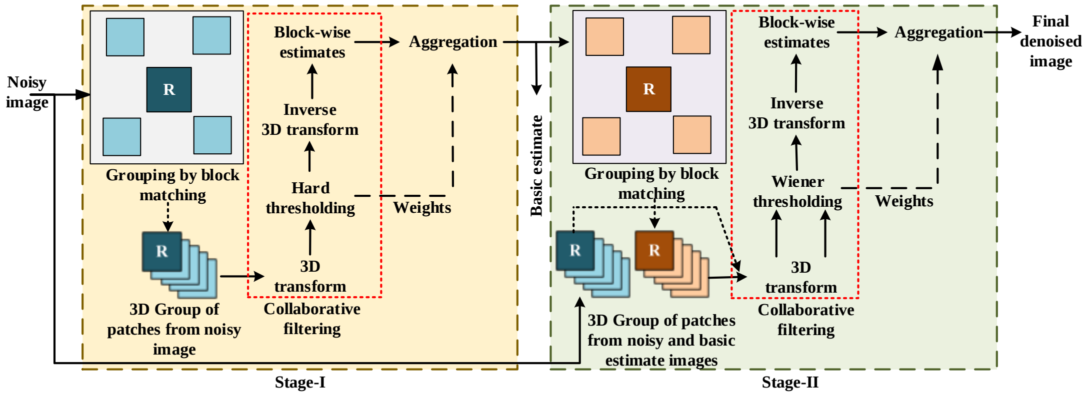

Figure 6.2: Block diagram of the conventional BM3D approach

6.3.2 Proposed BM3D method

To improve the denoising performance of BM3D algorithm f........................

6.4 Experimental results

The performance of the proposed approaches is measured qualitatively and quantitatively ....

6.4.1 Fusion of spatial and transform domain approaches

Various spatial and transform domain ....

6.5 Summary

This chapter presents ....

Chapter 7

Conclusions and future directions

The research work presented in this thesis mainly ....

7.1 Conclusions

The research work embodied in this thesis has addressed the problem of ....

7.2 Scope for future study

There are many issues in ....

- The present research work can be extended to ....
- Images may be affected by multiple degradations like blur along with noise. ......
- Some new features may be exploited to enhance the denoising performance of the proposed algorithms.
- The proposed approaches can be extended to ....

List of Publications

Referred journals:

[**1**] **R. Verma** and R. Pandey, tile of paper-I," ***Journal name***, 2018, pages 1-22. **(SCI-indexed)**

[**2**] **R. Verma** and R. Pandey, tile of paper-II," ***Journal name***, 2018, pages 1-22. **(SCI-indexed)**

[**3**] **R. Verma** and R. Pandey, tile of paper-III," ***Journal name***, 2018, pages 1-22. **(SCI-indexed)**

[**4**] **R. Verma** and R. Pandey, tile of paper-IV," ***Journal name***, 2018, pages 1-22. **(SCI-indexed)**

International conferences:

[**1**] **R. Verma** and R. Pandey, "Paper title I," ***IEEE Conference name***, New Delhi, 2015, pp. 1-5.

[**2**] **R. Verma** and R. Pandey, "Paper title I," ***IEEE Conference name***, New Delhi, 2015, pp. 1-5..

Papers communicated in referred journals:

[**1**] **R. Verma** and R. Pandey, tile of paper-I," ***Journal name***, 2018, pages 1-22. **(SCI-indexed) (Under review)**

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