



**ENHANCEMENT OF ITERATIVE BACK  
PROJECTION TECHNIQUE FOR SUPER  
RESOLUTION IMAGE**

by

**AMIR NAZREN BIN ABDUL RAHIM  
(1440211319)**

A thesis submitted in fulfillment of the requirements for the degree of  
Doctor of Philosophy

**School of Computer and Communication Engineering  
UNIVERSITI MALAYSIA PERLIS**

2018

## ACKNOWLEDGMENT

First and foremost, I would like to convey my thanks to the Almighty for giving me the patience, strength, courage and determination during compiling this work.

I would like to extend my utmost gratitude to my role model and project supervisor, Assoc Prof. Dr. Shahrul Nizam Yaakob for his generous sharing his intellect, ideas and guidance throughout my research project. I would like to thank him for his friendship, empathy, patience and the time allocated in assisting me. I will be forever grateful for your honesty and support during my time as your postgraduate student. Also, my deepest thanks to Dr. Ruzelita Ngadiran for her invaluable comments and feedback.

Thanks to my dear parents, Abdul Rahim Abdul Malik and Norlia Sharifuddin for their prayers and their full support during my study. Not forgetting to my sister for their encouragement. I also would like to convey a gratitude to Ilman, Iszaidi, Che Muhammad Nor, Ezannudin, Wafi, Badrul Hisham, Wan Adia Nadia, Siti Asilah, Nur Waheeda, Farah Wahidah, Syamir Alihan, Rabiul Awal and other lab members for kindly help and guidance for this work.

I also wish to thank Malaysia Higher Education Minister (KPT) and University of Malaysia Perlis (UniMAP) for their financial support and giving me this opportunity. Last but not least, I would like to express my greatest appreciation to all the people who have helped one way or another in the writing of my research project. Thank you so much

May Allah accept our good deeds, forgive our sins and accept us in His paradise.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION OF THESIS</b>	<b>i</b>
<b>ACKNOWLEDGMENT</b>	<b>ii</b>
<b>TABLE OF CONTENTS</b>	<b>iii</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>x</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xiii</b>
<b>LIST OF SYMBOLS</b>	<b>xv</b>
<b>ABSTRAK</b>	<b>xvii</b>
<b>ABSTRACT</b>	<b>xviii</b>
<b>CHAPTER 1 : INTRODUCTION</b>	<b>19</b>
1.1 Research Significant	19
1.2 Background	20
1.3 Problem Statement	21
1.3.1 The IBP technique has difficulty to estimate the finest High Resolution image due to blurry effect.	22
1.3.2 The IBP technique commonly generates a huge number of iterations	22
1.3.3 The IBP technique is less robust toward noise effects.	23
1.4 Research Objectives	24
1.5 Research Scope	24
1.6 Research Organization	25
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>27</b>

2.1	Background	27
2.2	Concept of Super Resolution (SR) technique	27
2.3	Previous works on Super Resolution (SR) technique	30
2.3.1	Motion Estimation and Video Super Resolution	30
2.3.2	Image registration for Super Resolution	32
2.3.3	Quality of Enhancement for Super Resolution (SR)	34
2.3.4	Noise Reduction	37
2.3.5	Super Resolution in Colour Image	39
2.3.6	Face Recognition	40
2.3.7	Hardware Implementation	40
2.4	Category of Super Resolution techniques	41
2.5	Multiple Input Image based Super Resolution	43
2.5.1	Iterative Adaptive Filtering	44
2.5.2	Maximum Likelihood (ML)	45
2.5.3	Maximum a Posteriori (MAP)	47
2.5.4	Iterative Back Projection (IBP)	49
2.6	The Selection Technique	50
2.7	Challenges in Super Resolution	55
2.7.1	Blurred Image	55
2.7.2	Computational Efficiency	56
2.7.3	Robustness of Super Resolution	57
2.8	Quality Measurement	57
2.8.1	Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR)	58
2.8.2	Structural Similarity Index Measurement	59
2.9	Summary	62
<b>CHAPTER 3 : IMPLEMENTATION OF ITERATIVE BACK PROJECTION (IBP) TECHNIQUE</b>		<b>63</b>

3.1	Introduction	63
3.2	Problems of Observation Modelling	64
3.3	The Iterative Back Projection method	68
3.4	Imaging Kernel System	71
3.5	Improvement of the Initial Guess	75
3.6	Gradient Descent	78
3.7	Conjugate Gradient	79
3.8	Analysis and Discussion	85
	3.8.1 Image Quality	85
	3.8.2 Computational Complexity	92
	3.8.3 The Robustness toward noise effects	95
3.9	Summary	98
<b>CHAPTER 4 : THE ITERATIVE BACK PROJECTION (IBP) WITH EDGE ENHANCEMENT TECHNIQUE</b>		<b>100</b>
4.1	Introduction	100
4.2	Edge Enhancement	101
4.3	Edge Detection	104
	4.3.1 Derivative operator	105
	4.3.2 Template Based Edge Detection	107
	4.3.2.1 Sobel Edge detector	107
	4.3.2.2 Marr Hildreth Edge Detector	108
4.4	Advance Edge detector	110
	4.4.1 Canny Edge Detection	110
	4.4.2 Anisotropic Diffusion	115
	4.4.3 The IBP Estimation with Anisotropic Diffusion	117
	4.4.4 The Infinite Symmetrical Exponential Filter (ISEF) Edge Detector	119

4.4.5	The IBP Estimation with ISEF	122
4.5	Proposed of Sharp Infinite Symmetrical Exponential Filter (SISEF) Regularization	124
4.6	Proposed of Lorentzian Sharp Infinite Symmetrical Exponential Filter (LSISEF) Regularization	128
4.7	Discussion and Analysis	133
4.7.1	Situation 1: The performance of proposed techniques with variation of input images.	136
4.7.2	Situation 2: The performances of edge enhancement techniques with variety of blurry effects	145
4.7.3	Situation 3: The performance of edge enhancement technique toward variability of magnification scale	148
4.8	Summary	151
<b>CHAPTER 5 : THE ITERATIVE BACK PROJECTION (IBP) WITH DENOISING TECHNIQUE</b>		<b>153</b>
5.1	Introduction	153
5.2	Observation Model	154
5.3	Regularization	156
5.3.1	The Laplacian Regularization	157
5.3.2	Total Variation Regularization	158
5.3.3	Lorentzian-Tikhonov Regularization	159
5.3.4	Sobolev Regularization via Fourier Transform	161
5.4	Proposed of De-noising technique via Anisotropic Diffusion Clip (ADC)	161
5.5	Discussion and Analysis	171
5.5.1	Situation 1: Measurement for robust algorithm toward multiple kind noisy image	173
5.5.2	Situation 2: Measurement for robust algorithm toward multiple type of noises	182
5.6	Summary	186

<b>CHAPTER 6 :</b>	<b>CONCLUSION</b>	<b>188</b>
6.1	Introduction	188
6.2	Main Contribution	189
6.3	Minor Contribution	191
6.4	Future works	192
	<b>REFERENCES</b>	<b>194</b>
	<b>APPENDIX A Output Image for Chapter 3</b>	<b>206</b>
	<b>APPENDIX B Output Image for Chapter 4</b>	<b>208</b>
	<b>APPENDIX C Output Image for Chapter 5</b>	<b>212</b>

©This item is protected by original copyright

## LIST OF TABLES

NO.		PAGE
Table 2.1:	The evolution of IBP method improvement	52
Table 3.1:	Comparison of PSNR value	87
Table 3.2:	Comparison of SSIM value	87
Table 3.3:	Comparison of the iteration numbers for Gradient Descent and Conjugate Gradient method	93
Table 3.4:	Comparison of the PSNR of Gradient Descent and Conjugate Gradient toward AWGN	96
Table 3.5:	Comparison of the SSIM of Gradient Descent and Conjugate Gradient toward AWGN	96
Table 4.1:	List of Abbreviation Enhancement Technique	135
Table 4.2:	Measurement of PSNR for the IBP edge enhancement	136
Table 4.3:	Measurement of SSIM for the IBP edge enhancement	137
Table 4.4:	The performance comparison in number of iterations for the IBP edge enhancement	142
Table 4.5:	The PSNR performance comparison of the combination IBP with edge enhancement toward blind blurry effects	146
Table 4.6:	The SSIM performance comparison of the combination IBP with edge enhancement toward blind blurry effects	146
Table 4.7:	The PSNR performance comparison of edge enhancement techniques toward magnification scale.	150
Table 4.8:	The SSIM performance comparison of edge enhancement techniques toward magnification scale.	150
Table 5.1:	List of Abbreviation De-noising Technique	173

Table 5.2:	Comparison of PSNR for IBP with de-noising technique	174
Table 5.3:	Comparison of SSIM for IBP with de-noising technique	175
Table 5.4:	Comparison in the number of iterations for de-noising techniques	180
Table 5.5:	Comparison of PSNR toward multiple type of noises	182
Table 5.6:	Comparison of SSIM toward multiple type of noises	183
Table 5.7:	Comparison of number of iterations toward multiple type of noises	185

©This item is protected by original copyright

## LIST OF FIGURES

NO.		PAGE
Figure 2.1:	Taxonomy of Super Resolution techniques	44
Figure 3.1:	Common problems of the acquisition system (Sung Cheol Park,Min Kyu Park, 2003).	65
Figure 3.2:	The problems of observation model (Sung Cheol Park,Min Kyu Park, 2003)	66
Figure 3.3:	The imaging system kernel diagram	72
Figure 3.4:	Matrix transition	74
Figure 3.5:	The IBP algorithm pseudocode	76
Figure 3.6:	Flowchart of Overall IBP algorithm	77
Figure 3.7:	The pseudocode of Gradient Descent algorithm	79
Figure 3.8:	The Conjugate Gradient algorithm pseudocode	83
Figure 3.9:	Flowchart for implementation of Conjugate Gradient inside the IBP algorithm	84
Figure 3.10:	PSNR Chart for Magnify Scale of 2	88
Figure 3.11:	The detected image gradient for Gradient Descent technique (a) magnify scale of 2, (b) magnify scale of 3 and (c) magnify scale of 4.	90
Figure 3.12:	The detected image gradient for Conjugate Gradient technique (a) magnify scale of 2, (b) magnify scale of 3 and (c) magnify scale of 4.	91
Figure 3.13:	Repetition of the residual errors for Gradient Descent	94
Figure 3.14:	Iteration Chart for Magnify Scale of 2	95

Figure 3.15:	The Lena output image without noise (a) Gradient Descent method (b) Conjugate Gradient method	97
Figure 3.16:	The Lena output image with noise (a) Gradient Descent method (b) Conjugate Gradient	98
Figure 3.17:	The gradient of Lena output image with noise (a) Gradient Descent method (b) Conjugate Gradient	98
Figure 4.1:	Non Maximum Suppression with compare the edge strength	112
Figure 4.2:	The considered angles	114
Figure 4.3:	Hysteresis Threshold	114
Figure 4.4:	Flow Chart of Cheref Model (Cheref & Yousfi, 2014).	118
Figure 4.5:	Process flow of ISEF	121
Figure 4.6:	Flow Chart for Patel Design (Patel Shreyas A., 2013)	123
Figure 4.7:	Flow chart of IBP with Sharp ISEF regulator	125
Figure 4.8:	Sharper gradient image (a) Difference edge of HR (b) Edge of priori HR (c) Proposed Sharp Edge	128
Figure 4.9:	Lorentzian norm function and influence function (Patanavijit et al., 2007)	130
Figure 4.10:	Flow chart of IBP with Lorentzian Sharp ISEF regulator	132
Figure 4.11:	Reduction of ringing artefacts a) SISEF b) LSISEF c) ADC	141
Figure 4.12:	Graph of number of iterations for the IBP edge enhancement	143
Figure 5.1:	Overall flow of process in Anisotropic Diffusion Clip technique	165
Figure 5.2:	The clipping function	166
Figure 5.3:	Process to generate the clipping gradient	169

Figure 5.4:	Combination of IBP technique and Anisotropic Diffusion Clip	170
Figure 5.5:	Lena de-noising image (a) Gradient Descent (b) Conjugate Gradient (c) Sobolev (d) Total Variant (e) Laplacian (f) Lorentzian Laplacian (g) ADC (h) SISEF (i) LSISEF	178
Figure 5.6:	Graph of comparison in iterations for de-noising techniques	180
Figure 5.7:	Graph of number of iterations toward multiple type of noises	185

©This item is protected by original copyright

## LIST OF ABBREVIATIONS

1D	One Dimensional
2D	Two Dimensional
AD	Anisotropic Diffusion
ADC	Anisotropic Diffusion Clip
AWGN	Additional White Gaussian Noise
CAT	Computer Aided Tomography
CCD	Charge-Coupled Device
CG	Conjugate Gradient
CIDS	Colour and Intensity Distribution of Segment
CMOS	Complementary Metal-Oxide Semiconductor
CT	Computerized Tomography
DVF	Displacement Vector Field
GD	Gradient Descent
GEF	Gradient Exponential Filter
GGMRF	Generalized Gaussian Markov Random Filed
HR	High Resolution
HVS	Human Visual System
IBP	Iterative Back Projection
ICA	Independent Component Analysis
ICR	Iterative Convex Refinement
IIBP	Iterative Interpolation Back Projection
IID	Iterative Interpolation De-convolution
ISEF	Infinite Symmetric Exponential Filter
LoG	Laplacian of Gaussian
LR	Low Resolution
LSI	Linear Space Invariant
LSISEF	Lorentzian Infinite Symmetric Exponential Filter
MAP	Maximum a Posteriori
ML	Maximum Likelihood
MPREG	Moving Picture Experts Group
MR	Magnetic Resonance

MRF	Markov Random Field
MSE	Mean Square Error
PDE	Partial Differential Equation
POCS	Projection onto Convex Sets
PPLT	Point to Point Line Topology
PSF	Point Spread Function
PSNR	Peak Signal to Noise Ratio
ROI	Region of Interest
SDEF	Second directional Derivative Exponential Filter
SISEF	Sharp Infinite Symmetric Exponential Filter
SR	Super Resolution
SRUM	Super Resolution with Un-sharpening Mask
TGV	Total Generalized Variation
TV	Total Variation

©This item is protected by original copyright

## LIST OF SYMBOLS

dB	Industry standards measure SNR in decibel
log	The logarithm is the inverse operation to exponentiation
MAX <sub>r</sub>	Maximum intensity value existence in image
Y <sub>k</sub>	Multiple Low Resolution images matrices
D	Decimation parameter matrices
B	Blurry parameter matrices
W	Wrapping parameter matrices
X	High Resolution matrices
$\eta$	Additional noise parameter
$\sin \theta$	Sine with angle of theta
$\cos \theta$	Cosine with angle theta
$\xi$	Error estimated
exp	Exponential
$p()$	Probability function
$L()$	Likelihood function
argmax	Argument of maximum
argmin	Argument of minimum
$\sigma$	Variance of function
$\Gamma()$	Priori energy function
$\lambda$	Regularization parameter
$h_{bp}$	Back projection de-blurring kernel
$\alpha$	Multiplication enlargement factor
$Q$	Error relation matrix algorithm
$e$	The error between simulated and observed low resolution image
$\nabla$	Gradient function
$r$	Residual error
$s$	Conjugate residual error
$\beta$	Ratio of correlation residual error
$sup_x$	Supremum value along x axis
$Hf(x)$	Hessian function of $f$ along x axis
tan	Tangent
$\otimes$	Convolution operation
$\pi$	Pi or ratio of circle
div	Divergence operation
*	Multiplication of sparse matrices form
$\gamma()$	Thikonov Regularization
LoG	Laplacian of Gaussian
$\rho_{LOR}$	Lorentzian error norm function
$\psi_{LOR}$	Lorentzian influence norm function

T	Soft threshold
$\tilde{\epsilon}$	Median

©This item is protected by original copyright

# **PENAMBAHBAIKAN TEKNIK UNJURAN BELAKANG BERULANG UNTUK IMEJ RESOLUSI SUPER**

## **ABSTRAK**

Kajian ini membincangkan tentang penambahbaikan teknik Unjuran Belakang Berulang dalam Resolusi Super. Teknik ini mengalami kesulitan daripada penghasilan artifak deringan di sekeliling pinggiran imej yang kuat dan menggunakan sejumlah besar lelaran semasa proses anggaran. Selain itu, teknik ini mempunyai pretasi yang lemah semasa mengendalikan imej yang bising. Dalam usaha untuk mengurangkan artefak deringan, tesis ini mencadangkan pendekatan baru dalam pembinaan semula Unjuran Belakang Berulang dengan hibrid penambahbaikan pinggiran pengaturcaraan. Pertama, pengawal selia menggunakan Penapis Tajam Simetri Eksponen Tak Terhingga untuk memberikan bimbingan pinggiran yang benar dan tepat semasa unjuran belakang ke grid Resolusi Tinggi. Pinggiran yang tepat ini menghalang pembinaan semula Unjuran Belakang Berulang daripada dislokasi Resolusi Tinggi. Oleh itu, ia mengurangkan artifak deringan dan meningkatkan kualiti output secara purata sehingga 1.755 dB. Pengatur Penapis Tajam Simetri Eksponen Tak Terhingga ini membekalkan maklumat tambahan yang tepat dan membantu penganggar untuk menjimat 70% lelaran dari teknik konvensional dalam menentukan imej Resolusi Tinggi. Kedua, untuk meningkatkan kekukuhan pembinaan semula Unjuran Belakang Berulang, kajian ini mencadangkan penambahbaikan dengan pelaksanaan peraturan menggunakan Penapis Lorentzian Tajam Simetri Eksponen Tak Terhingga. Teknik ini dapat meningkatkan kadar penambahbaikan pinggiran selepas menetapkan tahap ketepuan Lorentzian lebih besar dari 1. Hasilnya, kualiti keluaran imej yang dihasilkan adalah meningkat secara purata sehingga 2.126 dB dan proses anggaran lebih jimat sehingga 63% lelaran semasa pembinaan semula Unjuran Belakang Berulang. Penapis Lorentzian Tajam Simetri Eksponen Tak Terhingga ini juga boleh melakukan pengurangan bising selepas menetapkan semula tahap ketepuan Lorentzian di bawah 1. Dalam pengurangan bising, teknik ini dapat meningkatkan kualiti pengeluaran secara purata sehingga 2.645 dB dan menjimatkan lelaran anggaran sehingga 78.2%. Ketiga, kajian ini diteruskan dalam meningkatkan keteguhan teknik rekonstruksi Unjuran Belakang Berulang dengan melaksanakan pengawalseliaan Klip Penyebaran Anisotropik. Pengawal Klip Penyebaran Anisotropik ini mempunyai keupayaan untuk menghapuskan kesan bising dalam banyak arah dan ia juga dilengkapi dengan teknik pemeliharaan pinggiran. Hasilnya, teknik ini dapat meningkatkan kualiti pengeluaran secara purata sehingga 3.134 dB dan lelaran anggaran dijamin sehingga 75.5%. Penemuan telah membuktikan bahawa kaedah yang dicadangkan ini meningkatkan teknik pembinaan semula Unjuran Belakang Berulang melalui penghapusan artifak, memelihara maklumat yang hilang dan mengurangkan implikasi bising. Selain itu, teknik yang dicadangkan ini lebih baik dari segi kualiti imej dan bilangan lelaran berbanding dengan teknik penambahbaikan pinggiran dan pengurangan bising yang lain.

# ENHANCEMENT OF ITERATIVE BACK PROJECTION TECHNIQUE FOR SUPER RESOLUTION IMAGE

## ABSTRACT

This study concerns in on improvements of the Iterative Back Projection (IBP) Super Resolution reconstruction technique. This technique suffers from self produces the ringing artefacts around the strong edge of the image and consumes a large number of iterations during the estimation process. Besides that, this technique has poor performances during handling the noisy image. In order to reduce the ringing artefacts, this thesis proposes a novel approach of the IBP reconstruction by hybrid with the edge enhancement regularization. First, the regulator uses the Sharp Infinite Symmetrical Exponential Filter (SISEF) to provide an accurate and precise edge guided during back projection to High Resolution (HR) grid. This precise edge guided prevents the IBP reconstruction from dislocating the HR projection. Thus, it reduces the ringing artefacts and increases the output quality averagely up to 1.755 dB. This SISEF regulator supplies accurate additional information and helps the estimator to save 70% iterations from conventional technique in determining the HR image. Second, in order to increase the robustness of IBP reconstruction, this study proposes an improvement with implementation of the Lorentzian Sharp Infinite Symmetrical Exponential Filter (LSISEF) regulations. This LSISEF technique is able to increase the rate of edge enhancement after set the Lorentzian saturation level larger than 1. As a result, the quality of the produced output image is averagely up to 2.645 dB and the estimation process is rapidly saving up to 63 % iterations in the IBP reconstruction. This LSISEF also can perform as noise reduction after reset the Lorentzian saturation level below than 1. In noise reduction, this technique is able to increase the output quality up to 2.645 dB and saving up the iterations of estimation up to 78.2%. Third, this study continues in improving the robustness of the IBP reconstruction technique by implementing the Anisotropic Diffusion Clip (ADC) regulator. This ADC regulator has the ability to remove noise effects in many directions and it is also equipped with edge preservation technique. Consequently, this technique is able to increase output quality averagely up to 3.134 dB and the iteration of estimation is saving up to 75.5%. The findings have proved that these proposed methods enhance the IBP reconstruction technique through removing the artefacts, preserving the lost information and reducing the noise implications. Also, these proposed techniques perform better in term of image quality and number of iterations compared to the other edge enhancement and noise reduction techniques.

## CHAPTER 1 : INTRODUCTION

### 1.1 Research Significant

This study focuses on the Super Resolution reconstruction algorithm, especially in the Iterative Back Projection (IBP) technique in order to deal with several limitations of IBP technique such as a preserves high frequency component (Cheref & Yousfi, 2014), oscillates between the same solutions (Nasrollahi & Moeslund, 2014) and unpleasant effects (Shah & Gupta, 2012). The examples of unpleasant effects are additional noise, ringing artefacts and aliasing effects. These effects always disturb the quality of the image. Precisely, the IBP technique is known as good performance in real image application when it capable to execute in parallel for faster hardware implementation (Michal Irani & Peleg, 1991). Indeed, the image applications require small time processing and less complexity computational algorithm. Furthermore, this study also provides some solutions which are edge guidance and noise remover to increase the robustness technique toward the aforementioned unpleasant additional effects.

The IBP was introduced by Irani and Peleg (1993). This technique is technically designed similarly with the reconstruction of 2 Dimensional projection from the 1 Dimensional projection in Computer Aided Tomography (CAT) ideas. Generally, this technique can be divided into three sub tasks which are image registration, interpolation and restoration. Normally, the image registration will take place in the first stage in Super Resolution technique procedure. At this stage, this task will do aligning process and combine the relative motion geometric of multiple input images. Meanwhile, the information for different motions are collected in advance. After completing the first stage task, the interpolation task will be performed to enlarge the resolution an aligned

input image by projecting to the High Resolution (HR) grid's size matrix. Then, reconstructing and restoring of HR image will occur at the final stage. Usually, this task manipulates the prior knowledge and any negative influence factors to the input image in order to determine the finer HR image. However, the IBP technique still requires some improvements, especially in the reconstruction part that enhancement of the algorithm in terms of robustness in lost information and noise effects can be done. The finding from the proposed technique in this study is useful for further developments and meets the demand of applications in the digital image.

## **1.2 Background**

Most applications in the digital image demand for higher quality image acquisition. The finest quality of image or High Resolution (HR) image is important to gain more useful information as possible. However, the image acquisition system introduces degraded output image or Low Resolution (LR) image in reality. There are many factors that contribute to this low quality of image. For instance, a finite number of resolution acquisition sensor may draw the limit information on the image. The motion blur is appeared when there is an occurrence of poor handling imaging system between the scenes. The system may introduce noise due to limitations of the device and additional signals during the transmission medium. An improvement on the sensor acquisition system would lead to expenditure budget, and unreliable for the real applications. Thus, image recovery through Super Resolution technique is the best choice to produce a finer image. Also, the goal of image recovery is to restore the number of degraded input images and transform to the better quality with enlargement of the size of output image.

In particular, this study is intended to investigate the constraints of the Super Resolution technique and provide some improvements. The design of the Super Resolution reconstruction technique is based on the imaging problem model. This model is designed based on the existence of several limiting factors in the real applications such as constraints in the Point Spread Function (PSF) of a camera that contains information of blur, translation and decimation factors. In addition, some constraints on the image acquisition may lead to the presence of global noise and contaminate the acquired image.

This research area is kept going for more five decades in order to provide effective solutions to handle the aforementioned problems. For example, several types of reconstructive techniques have been proposed such as a direct method, frequency domain reconstruction, and iterative based reconstruction (Bannore, 2009). However, the iterative based approach has been selected as one of the best designed techniques and gains high attention in the Super Resolution reconstruction development as such reported in the survey article (Nasrollahi & Moeslund, 2014). But, this approach suffers some weaknesses and limitations such as highly consumed high number of iterations, less robust toward noise effects and fail to preserve the lost information. Hence, the interest of this study is to offer an efficient solution in improving the features of the iterative based Super Resolution reconstruction. Also, the proposed technique would bring to light computation complexity and robust toward the blur and noise effects.

### **1.3 Problem Statement**

Several issues are identified as indicators when conducting this study.

### **1.3.1 The IBP technique has difficulty to estimate the finest High Resolution image due to blurry effect.**

The IBP reconstruction technique executes the de-blurring and enlarging process during reconstruction of the High Resolution (HR) image. This technique only performs well in removing the blurry effect if the image registration stage delivers an accurate blurry information. Yet, this technique still fails to preserve several lost in high frequency information due to blurry and decimation effects. The loss of high frequency information happens when the edge of the image is embedded inside the contour of an image.

Moreover, the ill-posed problem will arise after projecting the input image to the HR grid. The ill-posed problem occurs after the inversion of mathematical operation which produces bad interpolated result. Also, the edge of image cannot be well defined (Bertero, Poggio, & Torre, 1988). This is due to the very limited information from small size of input image. This interpolation process may eliminate the edge of the image due to randomly pick up the neighbour pixel value. Thus, to solve this edges image problem, the IBP technique requires an edge detector which will be enhanced into regulator to strengthen the possible weak edges and information (Cheref & Yousfi, 2014; Tan, Tao, Cao, Li, & Zhang, 2016).

### **1.3.2 The IBP technique commonly generates a huge number of iterations**

The large numbers of iterations give a negative impact on the performance of the IBP technique which will slow down the performance and unsuitable to be practically deployed in the digital image applications. The presence of this problem occurs when the estimation process attempts to converge toward one of possible solutions and then

oscillates between them (M Irani, Irani, Peleg, & Peleg, 1993; Nasrollahi & Moeslund, 2014). As a result, the complexity of computational may increase and consume a lot of time processing (Farsiu, Elad, & Milanfar, 2006a; Farsiu, Robinson, Elad, & Milanfar, 2004; Georgis, Lentaris, & Reisis, 2013; J. Yang et al., n.d.).

The injection of the very first initial HR resolution as initial condition is suggested by Peleg and Irani (1993). This injection value of HR gives large impact for the IBP reconstruction to determine the next possible truth of HR image (Michal Irani & Peleg, 1993). If the initial HR guess is closely reached to the truth HR value, it means that the technique only requires a few of iterations before reaching the best estimation. In short, the precision in the calculation of the initial guess helps to reduce the number of iterations during the reconstruction process which would yield to better performance of the system.

### **1.3.3 The IBP technique is less robust toward noise effects.**

During the reconstruction process, the IBP reconstruction technique tends to produce jaggy or ringing artefacts. This ringing effect is also known as the Gibbs phenomenon in mathematical terms. This undesired effect produces an annoying effect in the image and appears as ripple artefacts around the edges of the image. This problem arises when the IBP algorithm keeps on repeating the projection from low resolution grid to high resolution grid inversely without any edge guided (S. Dai, Han, Xu, Wu, & Gong, 2007; Patel Shreyas A., 2013; X. Yang, Zhang, Zhou, & Yang, 2015).

Furthermore, the IBP technique is not concentrating on the existence of additional noise in the imaging model. This has proved that this system has a weakness in handling noisy image. Additionally, the IBP reconstruction only implements an average operation

for noise reduction (M Irani et al., 1993). This technique also is poorly performed in differentiating useful information and additional noise elements inside the image. Thus the fusion of noise power inside the simulated image also happens in the reconstruction process. Therefore, in order to increase the robustness of the system, the regularization technique is deployed in order to overcome this problem and increase the robustness of the system (Cheref & Yousfi, 2014; Kohler et al., 2016; X. Yang et al., 2015).

#### **1.4 Research Objectives**

Based on the aforementioned problems, several objectives of this study are highlighted and divided into three main folds as follows:

- The first objective is to improve the IBP reconstruction algorithm by increasing the de-blurring quality image output.
- The second objective is to reduce the number iterations of the IBP reconstruction function.
- The third objective is to enhance the level of robustness of the IBP method toward the ringing and additional noise effect.

#### **1.5 Research Scope**

The scope of this study is converging to the implementation of the spatial domain Super Resolution, which has mainly contributed to the improvement of the Iterative Back Projection (IBP) method. This improvement includes the implementation of the edge enhancement and noise reduction techniques. Also, the light cost computation is another