UNIVERSITI PUTRA MALAYSIA

SUPER RESOLUTION IMAGING USING MODIFIED LANR BASED ON SEPARABLE FILTERING

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By

IKE CHIDIEBERE SOMADINA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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SUPER RESOLUTION IMAGING USING MODIFIED LANR BASED ON SEPARABLE FILTERING

By

IKE CHIDIEBERE SOMADINA

April 2019

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Recently, remarkable advances have been achieved in reconstructing high-resolution image from noisy, and low-resolution images. Reaching super resolution has been a challenge in image processing practices, because of their under-constrained nature that requires the missing HR image details to be reconstructed. In this research, the long-established single-image super-resolution problem is addressed by integrating the multiresolution property of Wavelet and the flexibility of Locally Anchored Neighbourhood Regression model to formulate a novel edge-based single image super resolution algorithm that allows robust estimation of missing frequency details in wavelet domain with complete enhancement procedure.

Firstly, the low resolution input image is decomposed into four frequency sub-bands, comprising of one approximate coefficient and three detailed coefficients sampled by applying discrete wavelet transformation. The underlying idea is to process and reconstruct information in low and high frequency sub-bands based on separable property of neighbourhood filtering to achieve fast parallel and vectorized operation, while enhancing algorithmic performance by reducing computational burden resulting from computing the weighted function of every pixel for each pixel in an image. We then processed the frequency sub-bands using the inverse discrete wavelet transforms which does not in any way increase image size, rather it reconstructs the original image with high integrity of preserved fine edge details and more realistic textures. Super resolution

is then achieved using the regularized patch representation (projection matrix) learned to predict the high resolution image features.

Lastly, we incorporate the nonlocal self-similarity prior to refine our reconstructed high resolution result; hence preserving the local singularity and edges details to achieve a more sophisticated, distinctive and robust image super resolution. Experimental results on standard images with qualitative and quantitative comparisons against several top-performing state- of-the-art SR methods demonstrate the effectiveness and stability of the proposed algorithm. The proposed method reaches the highest PSNR for scale factors of 2, 3 and 4, respectively for Set5 datasets with around 0.03-0.70 dB better than LANR, and 0.2-1.60 dB better than the second best method, i.e. ANR. Similarly, we achieved around 0.03-1.10 dB better than LANR, and 0.2-1.80 dB better than ANR for scale factors of 2, 3 and 4 on Set14 dataset.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

RESOLUSI SUPER MEMBAYANGKAN MENGGUNAKAN LANR YANG DIUBAHSUAI BERDASARKAN PENAPISAN BOLEH DIPISAHKAN

Oleh

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Baru-baru ini, penemuan berimpak telah dicapai dalam membina semula imej resolusi tinggi daripada imej resolusi rendah dan hingar. Mencapai resolusi tertinggi merupakan cabaran di dalam bidang pemprosesan imej kerana sifat terkawal yang memerlukan perincian imej HR yang hilang dibina semula. Dalam penyelidikan ini, masalah yang sudah lama dibincangkan iaitu image-tunggal resolusi-tertinggi ditangani dengan mengintegerasikan ciri pelbagai-resolusi daripada Wavelet dan fleksibiliti daripada model Regresi Kejiranan Berlabuh untuk merumuskan algoritma baru berasaskan imej tunggal resolusi-tertinggi yang membenarkan perkiraan tepat terhadap frekuensi terperinci yang hilang dalam domain wavelet disertakan prosedur lengkap penambahbaikan.

Pertama, input imej rendah resolusi dibahagikan kepada empat sub-band kekerapan, yang terdiri daripada satu anggaran pekali dan tiga sampel pekali dengan menggunakan transformasi wavelet diskret. Idea asasnya adalah untuk memproses dan membina semula maklumat di sub-band frekuensi rendah dan tinggi berdasarkan ciri yang dipisahkan oleh tapisan kejiranan untuk mencapai operasi selari dan vector yang pantas disamping meningkatkan prestasi algoritma dengan mengurangkan beban komputasi daripada pengiraan fungsi wajaran setiap piksel untuk semua piksel dalam imej. Kami kemudian memperoses sub-band frekuensi dengan menggunakan transformasi wavelet diskrit songsang yang tidak meningkatkan saiz imej, sebaliknya

ia membina semula imej asal dengan butiran halus berintigirti tinggi yang dipelihara dan tekstur yang lebih realistic. Resolusi-tertinggi kemudiannya dicapai dengan perwakilan patch regulatori (unjuran matriks) belajar untuk meramal ciri-ciri imej resolusi tinggi.

Akhirnya, kami menggabungkan persamaan bukan asli sebelum membaiki hasil pembinaan semula kami; dengan itu mengekalkan keunikan asli dan butiran halus untuk mencapai imej resoluso tertinggi yang lebih canggih, tersendiri dan mantap. Keputusan experiment pada imej standard dengan perbandingan kualitatif dan kuantitatif terhadap beberapa kaedah yang mempunyai prestasi terbaik state-of-the-art SR menunjukkan keberkesanan dan kestabilan algoritma yang dicadangkan. Kaedah yang dicadangkan mencapai tahap PSNR tertinggi dalam semua eksperimen pada dataset Set5 dengan sekitar 0.03-0.70dB lebih baik daripada LANR, dan 0.2-1.60dB lebih baik daripada kaedah kedua terbaik, contohnya ANR. Begitu juga pada dataset Set14, kami mencapai sekitar 0.03-1.10 dB lebih baik daripada LANR, dan 0.2-1.80dB lebih baik daripada ANR.

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Finally, I would like to thank my examiners for their time and constructive feedback.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

2D	Two Dimensional
AC	Approximation Coefficient
ANR	Anchor Neighbourhood Regression
AWGN	Additive White Gaussian Noise
BM3D	Block Matching and Three Dimensional Filtering
CWT	Continuous Wavelet Transform
DB	Decibel
DC	Detailed Coefficient
DWT	Discrete Wavelet Transform
FT	Fourier Transform
FFT	Fast Fourier Transform
FNLM	Fast Non Local Means
GR	Global Regression
HH	High-High
HL	High-Low
HR	High Resolution
HVS	Human Visual System
IDWT	Inverse Discrete Wavelet Transform
IBP	Iterative Back Projection
KSVD	K-Means Single Value Decomposition
LL	Low-Low
LH	Low-High
LR	Low Resolution
LWT	Lifting Wavelet Transform
LANR	Locally Regularized Anchor Neighbourhood Regression
MSE	Mean Square Error
MRF	Markov Random Framework
MRI	Magnetic Resonance Image
NN	Neighbourhood Embedding
NLM	Non Local Means
NNI	Nearest Neighbour Interpolation
NSS	Nonlocal Self-Similarity
NI-LBP	Neighbour Intensity of Local Binary Pattern
NE + LLE	Neighbour Embedding and Locally Linear Embedding
POCS	Projection-Onto-Convex-Sets
PCA	Principal Component Analysis
PSNR	Peak Signal to Noise Ratio
SI	Summed Image
SR	Super Resolution

SPN	Salt and Pepper Noise
SSI	Summed Square Image
SSIM	Self Similarity Index Metrics
SISR	Single Image Super Resolution
STFT	Short Time Fourier Transform
SWT	Stationary Wavelet Transform
SVD	Single Value Decomposition
T91	Train 91
WT	Wavelet Transform

CHAPTER 1

INTRODUCTION

Images processing is a field that has gained a lot of attention and continues to grow with new applications being developed rapidly especially in medical image analysis, aviation, surveillance, remote sensing, pattern recognition, space, forensic and military application to name but a few. These applications perform well with high resolution images acquired from surveillance devices and their performance are dependent on the quality of the acquired image. Due to the large technological advancement, image processing technology has become critical in twenty first (21st) century in situations where images are required for decision making purpose. Therefore, to obtain intrinsic information from a noise degraded image, it is necessary to first improve the image spatial resolution.

Super resolution is a software-based technique to reconstruct HR images using one or more LR images. It is one of the cost-effective solutions to compensate the hardware limitations of the imaging system to produce reliable results with a rich informative content. Super resolution reconstruction as a new technology, was first proposed in 1984 by **Huang et al**.

Figure 1.1: Single Image Super Resolution

Based on the application viewpoint, existing image Super resolution approach can be divided into three categories: interpolation-based SR

methods, reconstruction-based multi-image SR methods, and learning (example)-based SR methods.

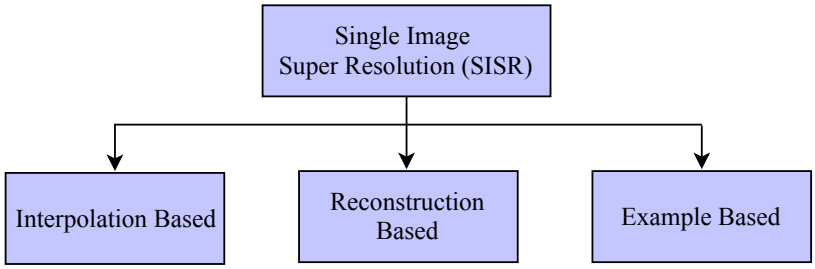

Figure 1.2: Categories Of Single Image Super Resolution

To resolve an LR image, interpolation based super resolution approach (e.g. nearest neighbour, bi-linear, bicubic, and etc.) uses an interpolation kernel to estimate the high frequency components. It is one of the age-old super resolution algorithm based on resampling. Despite being fast with low computational complexity, they are susceptible to blur high frequency component especially around the edges, thus producing undesired artifacts. This makes it inefficient to meet the demands of real-time practical applications. Recently, several approaches such as gradient profile prior and geometric regularity of image structure have been proposed so far to outperform interpolation based SR method. Reconstruction-based SR involves recovering high-resolution image from the degraded low-resolution image and its considered a large-scale problem because it requires constant calculations resulting to a large computational cost. Considered as ill-posed estimation problem, there is need to effectively enhance SR performance of the reconstruction process especially when the magnification factor becomes high. In view of this, many prior knowledge such as adaptive filtering approach, projection-onto-convex-sets (POCS), iterative back projection has been proposed. Lastly, learning (example)-based single image SR (SISR) uses machine learning technique to learn edge information from natural images and it has achieved state-of-the-art. Learning-based methods have been used to overcome the magnification factor limitations in interpolation and reconstruction based SR method but its representation of the high-frequency component of an HR image is still an active research problem. This provides the motivation for the development of other techniques to achieve a more sophisticated image Super Resolution.

In this research, a new edge-preserving single image super-resolution reconstruction was proposed based on wavelet analysis. Wavelet plays an important role in decomposing and effectively capturing intrinsic edge features that possess the multi-resolution characteristics that reflects the features of an image which the human visual system is more sensitive to. Experimental results on our algorithms showed a sharp reconstructed high-resolution image and compared with the existing traditional as well as top performing state-of-the-art super-resolution methods in terms of Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM). Furthermore, additional experiments to show the superiority of the proposed method was performed.

1.1 Motivation

The main idea behind this thesis is the estimation a noise-free image from the noisy or degraded image by a learning-based SISR method in wavelet domain. In spite of several algorithm developments to achieve outstanding performance, there are still scope for further improvement. To achieve the desired result, it is important to first select an efficient image denoising method to efficiently suppress the degradation as well as preserve image fine structures and other detailed features as much as possible. Moreover, for real-time and online applications, it is essential to have a computationally efficient algorithm to achieve image denoising and reconstruction in a short time. Therefore, the objective of this research work is to develop an efficient SISR algorithm that is based on separable property of neighborhood filtering in wavelet domain to generate image with high degree of preserved edge details and texture. The performance of our proposed algorithm is contrasted with other existing state-of-the-art methods.

1.2 Problem Statement

In spite of rigorous developments made so far in this field, there are still certain issues as regards its practical use in real time scenario that is still a problem due to computational efficiency (**Yang et al, 2008, Zongqing et. al 2017**). Although various denoising approach have been previously proposed to remove noise from an image while preserving the image edges but there is still scope for future research to improve the performance.

The basic problem in existing SISR techniques is in estimation robust high frequency components and effectively reconstructing these high

frequency components without losing fine image details. Conventional as well as advanced methods maintain the quantitative measures, but still faced with aliasing and blurring effects around edges (**Chang et al. 2004, Zeyde et al. 2010, Nikita et al. 2016**), hence failed to saliently preserve edges and generate a plausible image visual quality. Edge preservation is a challenge task in image super resolution. We present a good method that is adaptive to edge directions to produce high-resolution images with high degree of preserved local edge details and texture. In addition, we explained mathematical model used to predict the final high-resolution results.

1.3 Aim And Objectives Of Research

The aim of this research is to develop technique to solve both the challenges of preserving the local edge structures and improving image visual quality in Single image super resolution (SISR).

The objective of this research can be further be formulated as follows:

1. To improve on the estimation of robust high frequency coefficients obtained by separable filtering of sub-bands in the wavelet domain to recover coded or hidden information from original low resolution (LR) image.
2. To enhance image reconstruction performance to obtain a visually improved HR image with high PSNR values as well as SSIM values with ranges between 0 to 1. SSIM values closer to 1 indicates that two images are perfectly structurally similar with higher reconstruction quality.
3. To qualitatively and quantitatively explore single image SR, especially on benchmark datasets of low resolutions and compare the proposed edge preserving approach with other state-of-the-art-methods.

1.4 Scope And Limitations Of Research

This study focuses on the use of the multi resolution property of a wavelet to decompose the given image data into lower (coarser approximation) and higher details (horizontal, vertical, and diagonal edges) to interpolate the missing pixels in them separately in order to avoid the over-smoothing and over-sharpening of the salient information.

There are several limitations of the current study. First, we did not evaluate the effect of super resolution on images of different noise textures. Second, we did not explore resolution improvement greater than a scale factor of 4. In reality, spatial resolution improvement by a factor of 4 provides a high-resolution result with finer details at the edges. Third, because single image super resolution (single-frame) is widely applicable than multiple-frame SR approaches, we limit our research only to the single image super resolution and did not consider multi-image super resolution techniques.

1.5 Thesis Organization

The layout of this thesis is divided into five chapters. General description to the contents of the chapters is summarized as follows:

- Chapter 1 provides a brief introduction to image super resolution and its application. Furthermore, this chapter states the motivation, presents the problem statement, aim and objectives and lastly, the scope and limitation of research.
- Chapter 2 discusses preliminaries needed to be properly understood and then presents literature study of image denoising and reconstruction. Furthermore, related journals and publications are reviewed and used as reference to this project.
- Chapter 3 proposed our methods. This chapter introduces in details the mathematical model used in our proposed method to predict the final high-resolution image.
- Chapter 4 evaluate and discusses the results of the proposed methods and also introduces a comparatives study with the state-of-the art approach. Performance evaluations using computer simulations are also discussed.
- Chapter 5 summarizes and concludes the full project and also propose future work.

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PUBLICATIONS

Ike S. Chidiebere, Nazeer Muhammad, Nasri B. Sulaiman, "*Separable Super resolution imaging using modified LANR based on Separable filtering*". Submitted to International Journal of Pattern Recognition and Artificial Intelligence.

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