Implementation of Image Super-Resolution on Raspberry Pi

by

Comfort Abiodun Iyanda
(1632322285)

A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science (Embedded System Design Engineering)

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2017

DECLARATION OF THESIS

Author's full name : Comfort Abiodun Iyanda

Date of birth : 22/12/1987

Title : Implementation of Image Super-Resolution Technique on Raspberry Pi
.....

Academic Session : 2016/2017

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)*

■ **OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy Or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

_____ **SIGNATURE**

_____ **SIGNATURE OF SUPERVISOR**

_____ **(NEW IC NO. / PASSPORT NO.)**

_____ **NAME OF SUPERVISOR**

Date :_____

Date : _____

NOTES: * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction

ACKNOWLEDGEMENT

My foremost gratitude goes to God Almighty who has been my anchor and source of strength at every single stage. God in His plenteous mercy have extended His hands of grace unto me to complete this thesis. This thesis would not have been completed without the support and assistance of many people. Firstly, to my Husband, Mr. Akintunde Temitope Ogunwola, who has sacrificed immensely (both emotionally and financially) to my study in Malaysia. Your unique attribute to see me flying has encouraged me till this stage of my study. A special gratitude to my beloved parents, Mr. J. O. Iyanda and Mrs. Felicia Iyanda, for believing and teaching me to always reach for the peak. Your prayers, sacrifices and love can never be forgotten.

Secondly, I would like to express my deepest gratitude to my supervisor Dr. Phak Len Eh Kan, for his expertise, understanding, patience and enthusiastic encouragement and useful critiques to my project work.

I would like to extend my gratitude to all the academic lecturers of the School of Computer and Communication Engineering. Thank you all for your love and supports throughout the course of this program. May God bless you all.

I would not forget to extend my sincere appreciation to the members of Perlis Grace Centre, thanks for giving me the chance to serve in different capacities in God's vineyard. Finally, a very special thanks to the Nigerian community in UniMAP who have taken me not just as a friend, but as a Sister. May God strengthen every one of you in your pursuits and grant you victory on every side

TABLE OF CONTENTS

.

LIST OF FIGURES

(j)SR of Tyre image executed on RPi

(k) SR of Words image executed on GPC.

(l)SR of Words image executed on RPi.

LIST OF TABLES

LIST OF ABBREVIATIONS

SR	Super-Resolution
LR	Low Resolution
HR	High Resolution
IBP	Iterative Back-Projection
POCS	Projection onto Convex Sets
MAP	Maximum a Posteriori
CCD	Charge-Coupled Device
SRR	Super-Resolution Reconstruction
FPGA	Field Programming Gate Array
DSP	Digital Signal Processor
SBC	Single Board Computer
RPi	Raspberry Pi
LLE	Locally Linear Embedding
USB	Universal Serial Bus
CPU	Central Processing Unit
RAM	Random Access Memory
HDMI	High-Definition Multimedia Interface

GPIO	General-Purpose Input/output
VNC	Virtual Network Computing
IP	Internet Protocol
GUI	Graphical User Interface
SSH	Secure Shell Host
OS	Operating System
PSNR	Peak-Signal-To-Noise-Ratio
MSE	Mean Square Error

Pelaksanaan Teknik Pengimejan Super-Resolusi Pada Raspberry Pi

ABSTRAK

Sejak beberapa dekad lalu, proses untuk mendapatkan imej yang lebih berkualiti merupakan sekatan yang perlu diatasi dalam bidang pemprosesan imej. Imej yang mempunyai resolusi tinggi menjadi suatu keperluan yang berterusan. Secara langsung, imej yang mempunyai kualiti yang terbaik adalah penting dalam aplikasi-aplikasi tertentu. Contohnya, dalam jabatan forensik, imej diperbesarkan dari segi saiz supaya ahli penyelidikan boleh mendapatkan sebanyak mungkin informasi megenai experimen berkaitan. Kemerosotan kualiti imej yang disebabkan oleh kekaburan (akibat daripada gerakan tempat kejadian, salah tumpuan, dan pergolakan atmosfera, serta fungsi titik penyebaran), bunyi bising sensor (kepekaan pengesan, ketidaksempurnaan optik dan perubahan alam sekitar) dan *aliasing* (akibat daripada pensampelan bawah atau pensampelan lulus jalur) – hasil daripada proses untuk mendapatkan imej melalui penggunaan alat untuk merakam imej (kamera). Teknik super resolusi digunakan untuk mengimbangkan kesan negatif ini dengan membina imej resolusi tinggi daripada imej resolusi rendah tunggal atau berbilang, untuk memudahkan proses untuk memperolehi kandungan visual yang lebih baik and juga proses pengecaman tempat kejadian. Terdapat banyak aplikasi di mana imej yang berkualiti tinggi diperlukan, seperti penderiaan jarak jauh, pengimejan satelit, pengawasan, pengimejan perubatan dan lain-lain. Dalam tesis ini, gambaran keseluruhan tentang cara-cara yang berbeza untuk mendapatkan imej yang mempunyai super resolusi; huraian teknik-teknik tersebut, merangkumi kebaikan dan keburukannya; cara-cara penambahbaikan imej yang diperkenalkan baru-baru ini akan dibincangkan. *Iterative back-projection (IBP)*, salah satu kaedah super resolusi, dilaksanakan dengan *Raspberry Pi* untuk menganalisis prestasinya dan ketepatan dalam pengukuran kemantapan bunyi bising. *MATLAB* digunakan untuk mereka bentuk algoritma yang diperlukan. Algoritma tersebut kemudian dijalankan oleh *Raspberry Pi* dengan penggunaan aplikasi *GNU Octave*. Prestasi *IBP* disahkan dengan pengiraan *MSE* dan *PSNR* masing-masing.

Implementation of Image Super-Resolution on Raspberry Pi

ABSTRACT

Improving image quality has been a bottle neck of image technology for the past few decades. High resolution is a continuous and on-going need and it becomes essential to have the best quality of image in some applications such as in forensic department where in order to receive maximum possible information, image has to be enlarged in terms of size. Image degradation that is caused by blur (as a result of motion of the scene, wrong focus and atmospheric turbulence and point spread function), sensor noise (detector sensitivity, optical imperfections and environmental changes) and aliasing (as a result of under-sampling) is produced in the process of acquiring image through an image acquisition device (Camera). Image super-resolution technique is used to compensate these degradations factors by reconstructing a high resolution image from single or multiple low resolution images to facilitate better visual contents and scene recognitions. There are many applications in which high quality image is required such as remote sensing, satellite imaging, surveillance, medical imaging etc. In this dissertation, an overview of different approaches to super resolve an image is provided, how the techniques works along with their pros and cons accordingly, recent improvements carried out by different researchers is also included. Iterative back-projection (IBP) which is one of the methods of super resolution is implemented on a Raspberry Pi in order to analyse it performance and accuracy measuring it robustness to noise. The IBP approach is conducted by starting with an initial estimate of the SR image, and then it compares the projected LR results with the observed images and updates the HR estimate according to the errors that is predicted. MATLAB is used to design the algorithm and the same code is run on Raspberry Pi with the use of GNU Octave application. The performance of IBP is confirmed by calculating the MSE and PSNR respectively.

CHAPTER 1

INTRODUCTION

1.1 Overview

Image processing field has experienced steady growth over few decades in both hardware and software. Digital image processing is identified as the emerging trend. Digital image processing is used to extract useful information from images, enhance desired features for human interpretation and analysis with efficient storage and transmission. With the speedy growth and employment of image processing for visible interactions and display awareness, high resolution image becomes a strong need in almost all imaging applications for better visualization to unravel any fidelity issue and for extraction of extra information that may be needed for recognition (Tian & Ma, 2011). For example, in medical field, the radiologist uses imagery for detecting tumour accurately and many more. In remote sensing, a good regions classification in multi-spectral sensor systems is achieved through a high resolution image. It also helps in video surveillance systems where a more accurate identification of objects and persons of interest like a suspect's face and a car plate number are needed. Almost all image applications rely on high quality images for reliable and accurate analysis as well as prediction.

Image Super-Resolution (SR) technique is therefore applied to achieve the stated requirements. The goal of SR is to basically estimate a high resolution (HR) image from one or a sequence of low resolution (LR) or degraded image or observation. It aims at

overcoming the limitation of image acquisition devices (camera) where a sensor with few photo-detector produces a LR image (Chaudhuri, 2001).

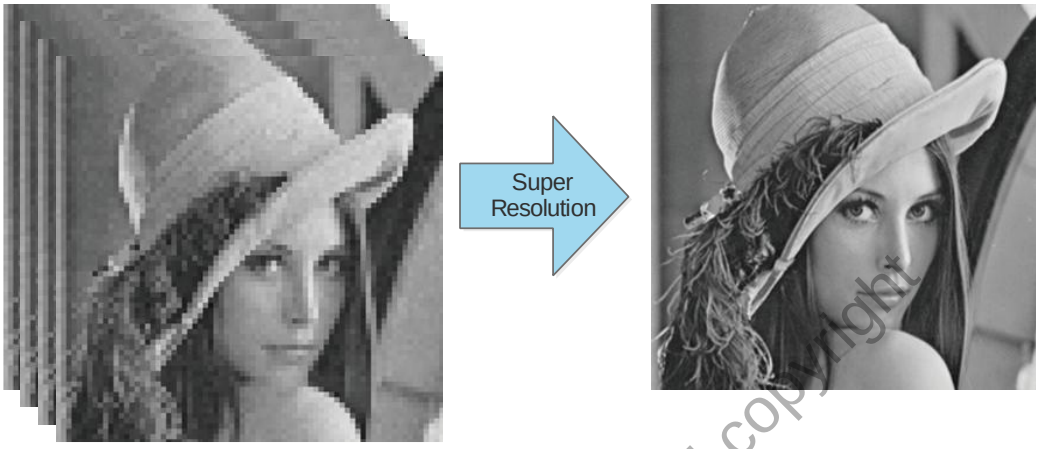

Figure 1.1: Example of SR using multiple LR image

SR can basically be implemented with single and multiple images. Figure 1 shows an example of SR where multiple low resolution is used to obtain an high resolution image in two domains namely Frequency and Spatial domains, the former was first implemented by (Tsai & Huang, 1984) for the purpose of reconstructing a HR image by removing aliasing which exist in low resolution images. After their work, a series of improved frequency domain SR reconstruction methods had been proposed (Bose, Kim, & Valenzuela, 1993; Rhee & Kang, 1999; Tekalp, Ozkan, & Sezan, 1992; Vandewalle, Süsstrunk, & Vetterli, 2006)), low computational complexity is a major advantage of frequency domain. However, the frequency domain method rarely incorporates prior knowledge and which limited their application in real time systems. For this reason, a wide variety of spatial domain SR reconstruction methods have been developed.

Super-resolution (SR) is a reconstruction technique that intends to compensate this degradation as mentioned earlier by reconstructing a high resolution image from this degraded images using either single or multiple low resolution depending on the design algorithm. Inspired by (R. Nayak, S. Monalisa, and Dipti Patra, 2013; Park et al., 2003), this work focuses on attempt to reconstruct HR image from multiple LR images from the same scene because each image is observed to contain more information to be represented in the eventual HR image. Consequently, the goal of SR is to combine the non-redundant information contained in multiple LR frames to generate a HR image. SR algorithm appears to resolve the factors that might limit the effective resolution of an imaging system has been noted earlier in this text such as aliasing due to under-sampling, noise from the sensor and blur that occurs due to optics and different external factors (motion of the scene, wrong focus, and atmospheric turbulence).

A typical SR algorithm involves three sub-tasks which include Registration, Fusion/Interpolation, and blur and noise removal. The LR images are first aligned mutually on a common coordinate system. This is generally referred to as image registration step. The aligned pixel values which usually results in a non-uniform sampling are interpolated to obtain a reconstructed HR image, subsequent de-blurring of the fused image results in better resolution image provided that a sufficient number of LR images are applied and the sub-pixel of the images are accurately aligned (Tian & Ma, 2011). These sub-tasks can be performed simultaneously and independently depending on the SR approach employed.

Typical spatial domain approaches includes non-uniform interpolation, iterative back projection (IBP), regularization, maximum a posteriori (MAP), learning based and projection onto convex sets (POCS). A simple approach that enhances image resolution is non-uniform interpolation such as bilinear or cubic interpolation. However, various

studies show that this type of approach cannot compensate the lost information during the sampling process of the LR images (Park, Park, & Kang, 2003; Shou, Wu, & Zhang, 2014). The IBP approach first conducted by (M. Irani & Peleg, 1991) starts with an initial estimate of the SR image, then it compares the projected LR results with the observed images and updates the HR estimate according to the errors that is predicted. Several image SR reconstruction approaches used some regularization terms to solve the ill-posed problem (Hong, Kang, & Katsaggelos, 1997). Smoothness priors are usually incorporated as a constraint to reconstruct the HR image.

A statistical optimization framework based on a Bayesian estimation theory, namely MAP, was employed for image SR reconstruction due to its robustness and good performance (Chien, Leou, & Chen, 2011). The approach makes some simplifications and approximations on probability distribution models to achieve computational flexibility. Thus, obtained solutions may disrupt known SR constraints and all available a-priori information may not be completely utilized in the solution process.

The learning-based methods which make use of machine learning techniques often employ a dictionary generated from an image database. POCS algorithm is applied widely in image processing field because of its simplicity and flexibility to incorporate prior knowledge of solution, it was first introduced by (Stark & Oskoui, 1989), the results usually depends on the initial estimation because the solution can be more than one if the intersection of the sets is not a single point. Generally, the solution is non-unique since SR algorithm is ill-posed in nature. The computational cost is high with a slow convergence speed (Shang, Liu, & Sun, 2015). For example-based SR reconstruction, correspondences between HR and LR image patches are learned from a database, which are applied to each LR image to recover its most likely HR version.

Most example-based SR approaches involved a training set containing a large number of HR image patches and their corresponding LR image patches. Therefore, most learning-based SR reconstruction approaches treat the "learning" process as just a kind of "searching" the best-matched LR image patch, and then "pasting" the corresponding HR image patch (Chien et al., 2011).

1.2 Problem Statement

Image super-resolution is a research domain in digital image processing which utilizes one or more low resolution LR or down-sampled image of same scene to obtain a high resolution or up-sampled image. The requirement of any real imaging system is to produce a good quality image which means the image should be represented at a sufficiently high resolution. However, there is a limit to the spatial resolution that can be recorded by any digital device. For instances, the resolution of an image taken by a camera is dependent on the resolution of the CCD sensor, as the resolution of the image generated by a sensor increases, so does the cost of the sensor and thus, it may be too expensive (Shah & Gupta, 2012). The density of the sensor of a camera is indirectly proportional to the dimension of the sensor. The dimension of a sensor is made smaller in order to form a larger density sensor which in return produces a higher resolution and however, this is responsible for the generation of larger shot-noise.

The acquired image is also usually the degraded version of the original scene, the degradation in this images are mostly caused by different factors due to motion of the scene, wrong focus, atmospheric turbulence and optical point spread function responsible for blurred image.

Super-resolution reconstruction (SRR) algorithm is however not unique because of its ill-posed nature. The major issues in multiple images SRR algorithms are it sensitivity to registration error due to the need for motion estimation and computational cost and complexity. SRR may result to degradation image instead of image improvement if the registration process is wrong. This degradation is usually called registration error noise and depending on the characteristics of both the registration algorithm and the image being processed. IBP algorithm is employed among other SR algorithms because of its low computational complexity that can be applied in real time applications. HR image obtained with IBP is, however prone to ringing artifacts mostly around the edges because of the inability to control the back-projection process and image registration process algorithm and noise removal model (Yang, Zhang, Zhou, & Yang, 2015).

Good effort have been carried out by different researchers to suppress this artifact, some paper proposed edge detection algorithm to preserve the edges, some utilized statistical algorithm and some have proposed the learning based algorithms. Most of the propositions have been carried out in a simulated environment like the use MATLAB according the literature. These works focuses on analysing the performance of IBP algorithm in embedded system in terms of the accuracy and probably observe the artifact intensity on real device instead of simulation environment because computational complexity is critical for real time hardware and software implementations. It is, therefore important to compare and confirm the performance accuracy using the necessary image metrics.

1.3 Aim and Objective

The main aim of this research is the implementation of SR algorithm on a Raspberry Pi platform while investigating the performance accordingly. This includes:

i) To develop and implement image SR algorithm based on IBP using MATLAB and Raspberry Pi 2 B+ respectively.
ii) To validate the performance of image SR algorithm on Raspberry pi 2 B+ in comparison with General Purpose Computer using image metrics including PSNR, and MSE.

1.4 Research Scope

This project comprises of two stages; software and hardware platforms. The software used in this project is MATLAB. MATLAB is used to test run the multiple LR SR based algorithm focused for this project known as Iterative Back Projection (IBP) technique before applying them into hardware. The same piece of algorithm is implemented on Raspberry Pi. Six different types of colour still image dataset are taken from the literature.

1.5 Dissertation Organization

This dissertation organized in five chapters and the contents of each chapter are as follow

- Chapter 1 presents the background of the topic, motivation and problem statement for this research, objectives and research scope alongside this chapter cover the organization of this work.
- Chapter 2 is a literature review. This chapter includes comparison between frequency domain and spatial domain Image super-resolution techniques. Observation model and reviewed the previous work on spatial domain image super resolution, background and general information on Raspberry Pi is explained and finally, the review of different image processing implementation in Raspberry Pi.
- Chapter 3 covers a methodology. This chapter presents the method applied in this project, full block diagram of this project, the process flow of IBP technique and the description of each algorithms used. Furthermore, implementation of the technique in Raspberry Pi is presented.
- Chapter 4 describes the results of implementing the IBP algorithm and details explanation of it.
- Chapter 5 concludes the achievement of this project objective with the recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Super-resolution (SR) image reconstruction techniques can be implemented and tested in a software and hardware domain. This algorithm have been extensively tested, analysed and improved in software most especially by applying simulation in MATLAB. The historical improvement of SR algorithm is discussed and a review of previous work in this field is carried out, researchers who implemented these algorithms on hardware, such as FPGA, DSP board, and SBC is also discussed. The reason for choosing to use Raspberry Pi (RPi) over the other hardware is also being justified. Finally, a review of image processing algorithms that have been implemented on RPi is discussed. General information about RPi is also disclosed here.

2.2 Overview

Many researches have been carried out on SR over the last two decades. The earliest approach of SR was attempted by (Tsai & Huang, 1984). Thereafter, numerous approaches has been proposed since then until today and these methods can be categorised into two main groups known as Single and Multiple image super-resolution methods. Most earlier SR researchers have utilized multiple LR image of the same scene to reconstruct HR image but recently that the researches is carried out more using