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A Review: Image Super Resolution Reconstruction Techniques and Challenges

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Abstract—Super Resolution Image Reconstruction is a process of recovering High Resolution image which is degraded. The aim of Super Resolution is to improve the visual quality of available Low Resolution images. This paper covers the techniques and challenges of Super Resolution Image Reconstruction. Comparison of all the methods with its advantages and disadvantages is also identified.

Keywords — Low Resolution, High Resolution, Super Resolution, Image Reconstruction, De-noising.

I. INTRODUCTION

Image Reconstruction is a process which improves the quality of image by estimating amount of noise and blur involved in image. With the passage of time, Image gets distorted by atmospheric and environmental effects. Degradation comes in many forms such as Motion Blur, Noise and Camera Misfocus [1].

The Super Resolution Image Reconstruction produces High Resolution Image from sequence of Low Resolution Images by taking more samples of the same scene and merges the samples to get High Resolution Image. Multiple scenes can be obtained by several clicks or from multiple cameras located in different positions. Super Resolution Image Reconstruction consists of three components [2]: (i) Registration is used to map the motion from Low resolution Frame to common reference frame. (ii) Interpolation refers to the mapping of motion corrected pixels to Super Resolution grid. (iii) Reconstruction is used to remove blurring and noise.

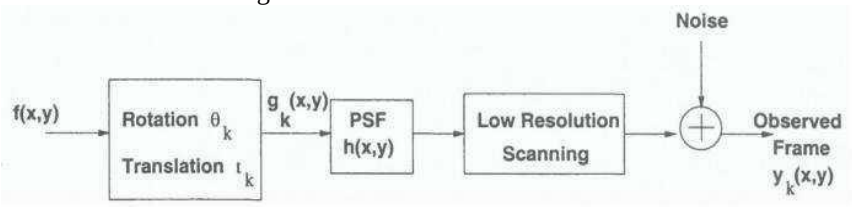

Figure 1 Observation Model relating a High Resolution Image to Low Resolution Frames.

Figure above shows the observation model which relates the HR image to LR frames. The input signal f (x,y) is continuous Image in co-ordinate system (x,y) . Motion is purely modelled as rotation and translation. The effects of LR sensor and optical blur is modelled as convolution of g_k (x,y) with blurring kernel h(x,y). Finally image undergoes the LR Scanning followed by Noise [2].

The major advantage of SR approach is that it is less costly and existing LR system can be still utilized. The SR image reconstruction is widely used in medical imaging(CT & MRI), satellite imaging(remote sensing, ROI & LANDSAT), Video applications, Surveillance, Forensics, scientific, Digital Video Recorder (DVR).The basic problem with SR image reconstruction is multiple LR frames are required to obtain HR image [3].

II. SUPER RESOLUTION IMAGE RECONSTRUCTION APPROACHES

A. Frequency Domain Approach

Frequency Domain Method use aliasing of LR image to restore the HR image. It falls into three categories [2]: (i) shifting property of Fourier Transform, (ii) Aliasing relation between continuous Fourier transform (CFT) of HR image & discrete Fourier transform (DFT) of LR image and (iii) on the assumption of original HR image is band limited. These properties design the system equation relating DFT & CFT. The advantages of frequency domain are theoretic simplicity, Low computational complexity and highly amenable to parallel implementation. Disadvantages include limitation to global translational motion and prior knowledge incorporation [3] [8].

B. Spatial Domain Approach

For Super Resolution Image Reconstruction, Frequency domain is relatively simple & computationally efficient. But there are some related problems [4]. (i) It restricts the inter frame translational because DFT assumes uniformly spaced samples, (ii) Prior knowledge of image is difficult to express in frequency domain.

However spatial domain eliminates the problem of frequency domain. Spatial domain support for unconstrained motion between frames & prior knowledge incorporation in solution.
The common spatial domain methods are as follow:

[I] Non uniform Interpolation Approach

Non uniform Interpolation SR algorithm reconstructs the function from samples taken at non uniformly distributed location [2]. Early SR methods use digital camera placement for accurate interpolation which requires accurate registration between images. New method is developed to overcome registration process by using multiple digital sensors with different pixel sizes.
The advantages of approach includes Low computational load and make real time application possible. However, for non uniform interpolation degradation models are very limited [3].

[II] Iterated Back Projection Approach

IBP procedure update the estimate of SR reconstruction by back projecting the error between images Y^j obtained in j^{th} iteration from model H, & the observed LR images Y. In each iteration, error values are added to the estimated image (F) pixels until it reaches the desired value [3] [5].

$$\hat{\mathbf{F}}^{(j+1)} = \hat{\mathbf{F}}^{(j)} + \mathbf{H}^{BP}(\mathbf{Y} - \hat{\mathbf{Y}}^{(j)})$$
$$= \hat{\mathbf{F}}^{(j)} + \mathbf{H}^{BP}(\mathbf{Y} - \mathbf{H}\hat{\mathbf{F}}^{(j)})$$

The disadvantage of IBP is, it does not include prior knowledge [4].

[III] Hybrid ML/MAP/POCS Approach

The ML-POCS hybrid method finds SR estimates by minimizing cost functional while constraining the solution within constraint sets. The constraint set map the down sampled version of HR image to the reference frame of LR sequences. The hybrid ML/MAP/POCS combines the benefits of stochastic approach and the POCS approach. The advantage of the hybrid approach is that all priori knowledge is effectively added and single optimal solution is achieved [2] [8].

[IV] Optimal and Adaptive Filtering Approach

The optimal adaptive approach has been used in many super resolution image reconstruction. The main limitation of optimal adaptive approach is in considering prior constrains as compared to POCS and Bayesian method [5].

C. Regularization Approach

Super Resolution Image Reconstruction is an ill posed problem which can be solved by Regularization approach. On the assumption of regularization parameters are estimated, the inverse problem can be solved by deterministic regularization by taking prior knowledge about the solution. The smoothness constrains use as prior knowledge [6].

D. Projection onto convex set Approach

POCS method is based on linear model, which describes the relation between LR & HR images. The cost function is formulated by linear model and HR image is obtained. However, the linear model used in POCS method is an ill-posed problem in a sense that its transformation matrix may be singular, so a unique solution cannot be obtained [5]. POCS algorithm has many advantages like its simplicity, it can be applied to cases with movement & can easily join the prior information, so this method is widely used. The disadvantages include non uniqueness of solution, slow convergence & high computational cost [2].

E. Sparse Representation Approach

Sparse representation method is based on single image super resolution which uses sparse signal representation. Image patches can be well represented by sparse linear combination of elements from an overcomplete dictionary. However, training overcomplete dictionary is a difficult problem. The dictionaries can be generated by simply randomly sampling raw image of same statistical nature [2] [7].
Two dictionaries can be trained for Low and High resolution image patches. So, the sparse representation of low resolution image patch can be applied with the high resolution image patch dictionary to generate a high resolution image patch [2]. The advantages of sparse representation include high computational capability and high SR mechanism. However learned dictionaries are required to reconstruct the HR image from LR image [3].

F. Neighbour Embedding Approach

Neighbour Embedding method is based on the assumption that small patches in LR and HR images forms manifolds with similar local geometry in two distinct spaces. Here, LR and HR images are represented as set of overlapping image patches and these each patch is represented by feature vector [2].

The Feature may be correlation, sum of entropy, sum of variance, sum of average, difference of variance, difference of entropy etc. This method is also called as learning based method for super resolution. Neighbour embedding method is very flexible and gives good empirical results [5].

III. CHALLENGES FOR SUPER RESOLUTION

A. Image Registration

In image processing, Image Registration problem is known as ill posed problem. The problem is more difficult when observations are of low resolution with heavy aliasing effects. As the resolution decreases, the performance of registration algorithm also decreases. Degradation by registration is more annoying then blur and noise effects.

B. Computation Efficiency

The computation complexity increases due to the large number of unknown samples. These samples require expensive matrix manipulation. Real time applications always demand for efficiency of SR algorithm.

C. Robustness

Super Resolution are vulnerable to deviation due to motion errors, noise, moving objects, inaccurate blur model, motion blur, moving scene etc.

IV. COMPARISON

Table 1: Comparison of Frequency Domain vs. Spatial Domain SR

	Frequency Domain	Spatial Domain
Motion Model	Global Translation	Almost unlimited
SR Mechanism	Limited	LSI or LSV
Noise Model	Limited	Very Flexible
Degradation Model	De-aliasing	De-aliasing A Priori information
Computation Requirement	Low	High
A-priori information	Limited	Good
Regularization	Limited	Excellent
Application Performance	Poor	Excellent
Applicability	Good	Almost unlimited

Table 2: Comparison of Various SR Image Reconstruction Algorithms

Method	Algorithm	Working	Advantages	Disadvantages
1	Frequency Domain Approach	Use aliasing that exist in LR image to reconstruct HR image	1) Less computation	1) Limited Noise & degradation Model
2	Spatial Domain Approach	Based on single image super resolution which is based on sparse signal representation	1) High computational capability 2) High SR mechanism	1) Learned Dictionaries required
3	Non uniform Interpolation Approach	Allows reconstruction of function from samples taken at non uniformly distributed Location.	1) Low computational Load 2) Makes real time application possible	1) Degradation Models are limited
4	Projection onto convex set Approach	Based on Linear model, describe relation between LR and HR, introduce cost function and Hr image is obtained	1) Simple to use	1) High computational cost 2) Slow convergence
5	Neighbor Embedding	Small image patches in low and high resolution images form manifolds with similarity	1) Flexible 2) Good Results	1) Not suitable for Large Data sets

V. CONCLUSION

In this paper various methods for Super-Resolution Image Reconstruction are discussed. Various methods for SR Image Reconstruction like Frequency domain method, Spatial domain method, Non-uniform interpolation, Neighbor embedding, POCS, Hybrid ML/MAP/POCS and other are discussed in this paper. It is observed that among various methods for SR reconstruction, Sparse representation with Learning dictionary is latest research area and is extensively used. At last the comparative table with working, advantage and disadvantages of all the methods is provided.

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