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Performance of super resolution algorithms in generating high resolution images

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Abstract

In recent days, requirement of high spatial resolution remote sensing data in various fields has increased tremendously. High resolution satellite remote sensing data is obtained with long focal length optical systems and low altitude. As fabrication of high-resolution optical system and accommodating on the satellite is a challenging task, various alternate methods are being explored to get high resolution imageries. Alternately the high-resolution data can be obtained from super resolution techniques. The super resolution technique uses single or multiple low-resolution mis-registered data sets to generate high resolution data set. Various algorithms are employed in super resolution technique to derive high spatial resolution. In this paper we have compared two methods namely overlapping and interleaving methods and their capability in generating high resolution data are presented.

Key words: Super resolution, Spatial resolution, Algorithms, Image quality assessment (IQA)

Introduction

The spatial resolution of image is defined as the smallest object that can be detected from the image. In satellite remote sensing, the resolution can be defined geometrically, as the projection of a detector on the target. The spatial resolution of an image is determined based on minute spatial detail that can be derived from that image. A high or fine resolution image provides more information than course one. High-resolution image data is widely used in many areas, such as geometrical information system, medical imaging, industrial product classification and security imaging.

The satellite remote sensing data is classified mainly by four different resolutions namely Spatial, Spectral, Radiometric and Temporal resolutions. The spatial resolution in remote sensing is the size of projection of pixel on the terrain or target. It can be defined other way as the size of smallest object which can be detected in the image. The highest spatial resolution of the optical system is dictated by the diffraction limit of optical systems and the detector size. The imaging electro-optical system are combination of optical system and the detectors like Charge coupled devices, CMOS detector etc. The detector size limited angular resolution of electro-optical system is based on the focal length of optical system and the pixel size of the detector. The spatial resolution of satellite remote sensing data is dictated by the focal length of the optical system, pixel size of the detector and the altitude of satellite.

In the satellite remote sensing the spatial resolution can be improved by three ways. They are (i) increasing the focal length of optical system (ii) reducing the pixel size and (iii) lowering the altitude of satellite. Increasing the focal length reduces the signal availability per unit area at the focal plane. As the size of the aperture controls the diffraction limited resolution, achieving very high-resolution data by increasing just focal length is not possible. The signal level and the diffraction limit can be improved by increasing the aperture size of the optical system. However, limitations of fabrication capability and accommodation of satellite with bigger payload in launch vehicle impose constraints in achieving large aperture optical systems. As detector size is controlled by solid state technology and with current technology smallest pixel size achievable is approximately seven microns. The reduction of altitude of the satellite below ~ 500 km, increases the atmospheric drag and reduces the life time of the mission. Due to these constraints achieving very high-resolution data directly from the satellite is a challenging task. High resolution imaging systems generates very high data rate, volume and transmitting it from satellite to ground station is difficult activity.

Due to these hardware limitations in producing high resolution image data, many researchers have proposed software-based resolution improvement techniques. These method of obtaining high resolution data is called as Super resolution. Super-resolution is the emerging technique of generating high-resolution images from one or more low-resolution images of the same scene/area. Based on the number of low-resolution image data used as input, the super resolution can be classified into single image super-resolution (SISR) and multi-image super-resolution (MISR). Compared to MISR, SISR is attractive as it need only one image as input. Super resolution can be achieved in frequency and spatial domain. Though the frequency domain methods have the advantages of theoretical simplicity and computational efficiency, they are not able to accommodate non-global translational motion models or spatially varying degradation [1]. Many spatial domain algorithms of super resolution have been developed to avoid these weaknesses of the frequency domain approaches. Following sections discuss these techniques in detail.

In the case of multi-image super resolution technique two are more mis registered low resolution images are employed. Many researchers attempted to acquire these low resolution misregistered images through hardware. They designed mechanism to make sub-pixel displacement of array detector between two exposure [2]. Another method attempted was with multiple looks for the same scene [3]. In the field of satellite remote sensing, the multitemporal images were used to generate high resolution image. The issues observed during these methods are:

1. The displacements between the available LR images are not known accurately;
2. Brightness variations between the images.
3. Cloud location change affects images as obstruction and shadows.
4. The change in scene between two images acquisitions time.

These constraints were overcome by the French space agency in SPOT-5 satellite system by having an arrangement to produce un registered two low resolution images. The electro-optical system of SPOT-5 had two 12000-pixel linear Charge coupled Devices (CCD) per band. These two linear CCDs were mounted with a shift between each other by half a pixel width in the linear direction [4]. These detectors captured images at the same time, two images with half-pixel shift in the imaging position. Leica ADS40 aerial cameras have adopted a similar imaging mechanism [5]

Typical spatial domain reconstruction methods include: non-uniform interpolation [6], iterative back projection (IBP) [7], projection onto convex sets (POCS) [8], Bayesian/maximum a posteriori (MAP) [9], hybrid MAP/POCS [10], multichannel deconvolution[11]and adaptive filtering [12].

Method and tools

In this study the multi-image super resolution method used for reconstructing high-resolution image. Many studies have reported generating high resolution data by interleaving two low resolution images[13]. In this study we have used both interleave and overlay and averaging method to generate high resolution image data.

A computer program was developed in Microsoft Visual Basic for this study. Function included in the software are low resolution image generation, zooming, high resolution image construction with interleaving and operlaying options and image quality evaluation using Mean Square Error(MSE) and Peak Signal-to-Noise Ratio (PSNR).

Low resolution image generation

In this study the low-resolution image set is generated from a high-resolution image. The method was examined with image of Marlin, Lena and lion Images. They are high, medium and low contrast images respectively.

Low-resolution Method 1

In the method-1 two sub sampled images are generated by selecting pixels of alternate row and alternate columns as shown in figure.1

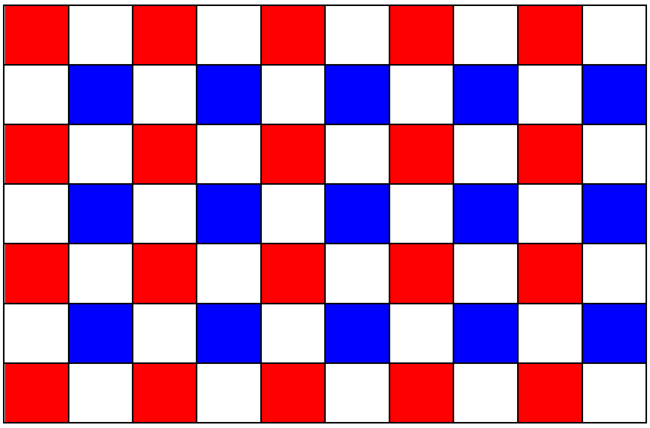

Figure 1. Sampling method to generate two sub sampled images by collecting alternate row and column pixels.

The pixels shown in red color generate one image and blue color generate another image. The data volume of low resolution set(two low resolution images) is half of the original high resolution image.

Low resolution Method-2

In the second method the two low resolution images are generated based on the concept of low-resolution camera with two detectors that are placed in staggered manner at focal plane. In this method, two low resolution images of same area, generated with pixel offset in both x and y direction.

Various steps involved in generating high resolution image are as given below.

Step. 1 Generate low resolution image by combining four pixels (2 x 2) from a high resolution image.

Step.2 Generate another low resolution image similar to the step 1 but starting from second row and second pixel.

Step. 2 Zoom both low resolution images(2X). This is done by replacing four pixels(2 x 2) with single pixel value od low resolution image.

Step. 3 Overlap these images one above another with one pixel shift along the row direction and one row shift.

Step. 4 Average the overlapped pixels to generate high resolution Image.

Process

Two low resolution images were generated by averaging four (2 x 2) pixel of original high-resolution image. The pixels of second image was generated with an offset of one row and one column.

The first image was generated by following equation

$$f(i,j)=1/4\ [g(2i-1,2j-1)+g(2i,2j-1)+ g(2i-1,2j)+ g(2i,2j)]$$

The second image was generated by following equation

$$f(i,j)=1/4\ [g(2i,2j)+g(2i+1,2j)+ g(2i,2j+1)+ g(2i+1,2j+1)]$$

Where f is sampled image and the g is the original image. The sampling method is depicted in the figure 2.

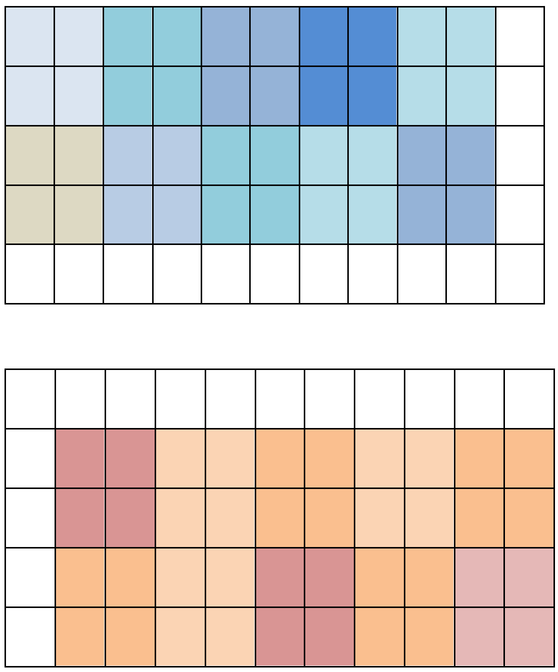

Figure. 2. The methods of low resolution images generated

In this method by averaging four pixels one pixels of low resolution image is generated. Final image is shown in the figure. 3

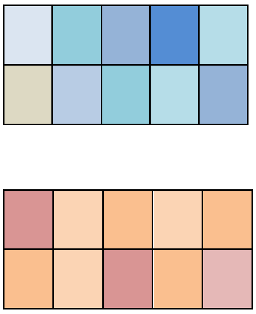

Figure. 3 Final sampled two low-resolution images

Zooming the low-resolution images

The low spatial resolution images are zoomed to twice the size in both x and y direction by adding rows and columns. Every four pixels(2 x 2) were assigned with the one pixel value of original low-resolution images.

The intensities assigned are as follows

B(i,j) =A(Round(i/2), Round(j,2))

i,j are number of columns and rows of new zoomed image. The zoomed images are shown in figure 4

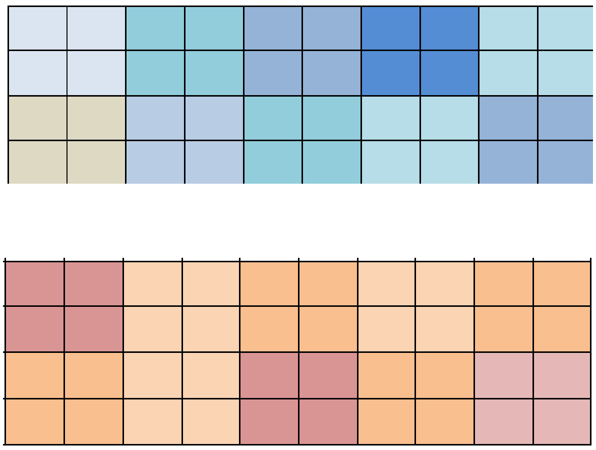

Figure 4. Zoomed images

Reconstruction of high resolution image

Reconstruction with two different methods are discussed here.

High resolution Method-1

Sub sampled images generated by the method -1 are combined in the interleaved way as shown in figure 5. The pixels shown in blue colour form first image and the pixels shown in red colour form second image.

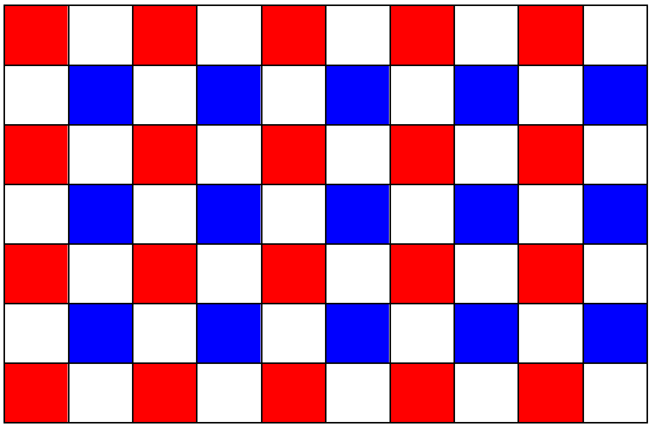

Figure 5. Sampling method to generate two sub sampled images by collecting alternate row and column pixels.

The pixels shown in white color are filled with a value derived by averaging four neighbor pixels(left, right, above and below).

High resolutionMethod-2

In the second method(overlapping and averaging), the high resolution image is reconstructed by overlapping these images and averaging the common area pixels from both images. It is important to note that the image sizes will reduce by one row and one column during the generation of low-resolution images and reconstruction time.

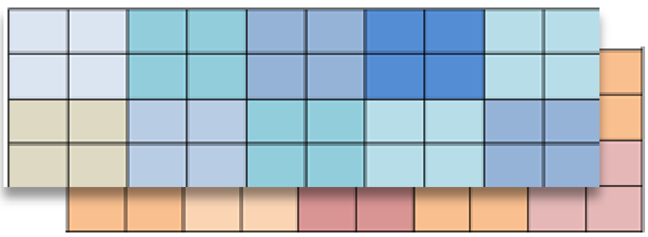

Figure 4. Overlapped images

The high resolution image was reconstructed by overlapping these images and averaging the common area pixels from both images. It is important to note that the image sizes will reduce by one row and one column during the generation of low resolution images and reconstruction time.

Four high resolution images were generated with four different combination

1. Low resolution method-1+High resolution method-1
2. Low resolution method-2+High resolution method-2
3. Low resolution method-1+High resolution method-2
4. Low resolution method-2+High resolution method-1

Image quality evaluation

Evaluation of image quality is important in any image processing activity to estimate the efficiency of the processing methods. Image quality can be evaluated by one of many methods available. These methods are used evaluate the image which is subjected to distortions during storing, processing, compressing, transmitting, image fusion, and biomedical imaging. They are divided into mainly two categories namely, into objective and subjective methods [11]. Subjective methods are based on human judgment and they work without reference to explicit criteria [12]. On the other hand, objective methods are functioning based on comparing different images or the statistical parameters of different images with explicit numerical methods [13,14]. Image quality is evaluated by many methods namely, Mean Square Error (MSE), Root Mean Square Error (RMSE), Peak Signal-to-Noise Ratio (PSNR), Universal Image Quality Index (UIQI), Structural Similarity Index (SSIM), Feature Similarity Indexing Method (FSIM) etc.

Among numerous image quality evaluation methods, the Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are used in many studies as they are simple to compute, implement, clear in physical meanings and convenient to implement mathematically [14].

P**eak Signal-to-Noise Ratio (PSNR)** is the ratio between the maximum possible value of a signal and the power of distorting noise that affects the quality of its representation. This quality measure is used to compare the original and reconstructed or degraded image. The high PSNR corresponds to less degradation or difference. As many image sample values have a very wide dynamic range, PSNR is generally expressed in terms of the logarithmic decibels (dB)

$$PSNR = 20\log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right)$$

Where is MSE ia Mean Square Error and is given below

$$MSE = \frac{1}{mn}\sum_{0}^{m-1}\sum_{0}^{n-1}\|f(i,j) - g(i,j)\|^2$$

F - matrix data of our original image

g represents the matrix data of our degraded image in question

m represents the numbers of rows of pixels of the images and i represents the index of that row

n represents the number of columns of pixels of the image and j represents the index of that column

MAX_f is the maximum signal value that exists in our original "known to be good" image

Table-1 Image-1 and results

Name	**Marlin**	**Lena**
Original Image		
Sampled zoomed Image-1		
Sampled zoomed Image-2		

Recons- tructed Image		
Difference Image Absolute (Original - Recons- ructed)		
MSE PSNR	35.88 73.72	13.45 83.11

Table-2 Image-2 and results

Name	Marlin	Lena
Original Image		
Sampled and zoomed Image-1		
Sampled and zoomed Image-2		
Reconstru cted Image		
Differenc e Image Absolute (Original Reconstr ucted)		
MSE PSNR	315.13 51.99	240.29 54.28

Table 5 Results

		Marlin	**Lena**
Image-1	MSE	35.88	13.45
	PSNR	73.72	83.11

Image-2	MSE	315.13	240.29
	PSNR	51.99	54.28
Image-3	MSE	130.82	86.67
	PSNR	60.79	64.48
Image-4	MSE	130.40	83.31
	PSNR	60.82	64.76

Conclusion

In this study, two low resolution images were extracted from a high-resolution image using averaging, and subsampling methods. The algorithms of generating a high-resolution image from two low resolution images by two different methods namely overlapping and interleaving are explained and demonstrated. The image quality of reconstructed image compared with the original image using mean square error (MSE) and peak signal to noise ratio (PSNR). In interleaving method at least 50 % pixels are same and remaining pixels are filled with averaging four neighborhood pixels but in the case of overlapping method, all pixel values are derived by averaging overlapped pixels. The interleaving method has shown better PSNR than overlapping Method. Among three images high contrast image has more error and less PSNR when compare with other images.

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