THE APPLICATIONS OF SR TECHNIQUES IN THE REMOTE SENSING

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ABSTRACT:

In order to improve the discriminability of the Remote Sensing (RS) images, super-resolution (SR) technology is widely applied in the RS. This paper gives a brief review of the SR approaches. The comprehensive comparation of both the frequency and the spatial domain methods is offered. And the theory principle of SR technology is presented with the designment of the SR CCD camera model. To the general image sequences, the process of SR restoration is discussed. Experimental results are reported for performance on both synthetic and real image data to demonstrae the success of applications in the RS. The conclusion of this paper and the work in the future are given in the end.

1. INTRODUCTION

During the process of imagery, many factors including the motion between the earth and the platform, atmosphere disturbance, out of focus, non-ideal sampling and so on, all make the images blurred and degraded. **SR** technology is the siginal processing based methods in software. It can remove the blur caused by the imaging system as well as recover spatial frequency information beyond the diffraction limit of the optical system. The task of **SR** image restoration from multiple undersampled and degraded images is to take advantage of the additional spatio-temporal information available in the image sequence. And the image with higher resolution than that of the original data can be constructed.

In recent years, **SR** technology has been rapidly growing. It has already been widely applied in the following areas: satellite imaging, video surveillance, video enhancement and restoration, video standards conversion, microscopy, digital mosaicing, aperture displacement camera, medical computed tomographic imaging, and so on..

SR technology is applied in the **RS** based on the following case. With the development of the **RS** technology, a large amounts of **RS** images of the earth with multi-platform, multi-sensor, multi-phase, multi-spectral can be obtained. In these data, there are considerable image data of the same area. But limitted by the manufacturing process of imagery equipment, these images are the undersampled of scene. At the same time the imagery equipment with high-resolution(HR) is very expensive and huge. So if we can synthesize **SR** technology with the low-resolution (LR) imagery equipment, we can reduce the cost and danger while improving the value of **RS** image data and the capability of detection for military target, Purportedly, France will apply this technology in the “SPOT5” launched in 2002. And the resolution will get to 2.5 from 5 meters. American EarthSat company has a test of this technology. Xi’an institute of optics and precision mechanics, academia Sinica also applys this technology in the designment of CCD camera model (QIN, 2002).

This paper first gives comprehensive review of the **SR** approaches. Then, the theory principle of SR technology is presented with the designment of the **SR** CCD camera model. Finally, experimental results are reported for performance on both synthetic and real image data to demonstrae the success of applications in the RS. And the conclusion of this paper and the work in the future are given.

2. A COMPREHENSIVE REVIEW OF THE SR APPROACHES

SR techniques may be divided into two main classes: frequency domain and spatial domain methods. All frequency domain approaches have realized the spatial resolution enhancement of LR image sequences via alias removal. This major class of SR methods mainly include reconstruction via alias removal, recursive least squares techniques and multichannel sampling theorem based techniques. In fact, all frequency domain approaches base on the seminal work of Tsai and Huang in 1984(Tsai, 1984). They utilize the shifting property of the fourier transform to model global translational scene motion, and take advantage of the sampling theory to enable effect restoration made possible by the availability of multiple observation images.

The second major division in **SR** literature——spatial domain techniques are mainly made up of these ways: interpolation of none-uniformly spaced samples, algebraic filtered backprojection, probabilistic methods, set theoretic methods. It is different from frequency domain techniques that they have respectively their restoration theory. With the **SR** development, spatial domain techniques will be more popular. At the present time, the MAP (Maximum A-Posteriori Estimation) formulation basing probabilistic methods is one of the most promising and flexible approaches to **SR** image reconstruction. It's only competitor of POCS (Project onto convex sets) in terms of convenience and flexibility.

We begin by presenting a tabular form comparison of the two main classes of **SR** reconstruction approaches –frequency and spatial domain. The table is divided into two sections. The upper portion deals with the formulation of the observation, motion and degradation models, while the lower portion makes generalizations concerning the solution approaches. It is important to realize that these are generalizations, and as a result, exceptions exist within the wide range of techniques we have discussed. We choose the most optimistic approaches within both the frequency and the spatial domain methods(Sean, 1998).

	Frequency Domain	**Spatial Domain**
Observation model	Frequency domain	Spatial domain
Motion models	Global translation	Almost unlimited
Degradation model	Limited	Linear Shift Invariant or Linear Shift Varying
Noise model	Limited	Very flexible, even spatially varying
SR Mechanism	Dealiasing	Dealiasing & bandwidth extrapolation using a-priori constraints
Simplicity	Very simple	Generally complex
Computation cost	Low	High
A-priori constraints	Limited	Almost unlimited
Regularization	Limited	Excellent
Extensibility	Poor	Excellent
Performance	Good for specific applications	Good

Table 1. The comparison of the two main classes of **SR** reconstruction approaches

It should be clear from this discussion that for **SR** reconstruction of scenes involving anything more than global translation motion, that spatial domain techniques are the preferred approach.

3. THEORY PRINCIPLE OF SR TECHNOLOGY

We first model the forward process that takes the ideal HR image to a degraded LR frame. Many imaging devices today, such as infrared and charged-coupled device(CCD)cameras, consist of arrays of light detectors. A detector determines area in the scene. Resolution of images produced by the camera is proportional to the density of detector array. But limitted by the manufacturing process of imagery equipment, these images are the undersampled of scene. Figure 1 shows a simplistic model of a CCD camera model (Nhat, 2000).

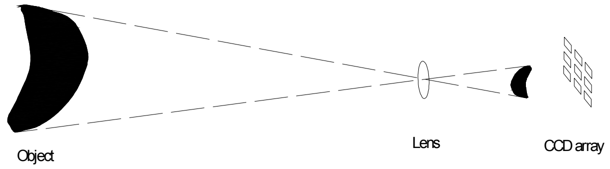

Figure 1. Traditional CCD camera model

The camera lens produces a blurred version of the object. The CCD array turns this degraded analog signal into a discrete 2-D image with quantized intensity values. In addition, the images are contaminated by additive noise from various sources: quantization errors, sensor measurement errors, model errors, ect. Ideally, we would like to have a high density CCD array placed in front of the camera lens to capture an undegraded HR image, and this HR image is what we seek to reconstruct. So we design the following **SR** CCD camera model.

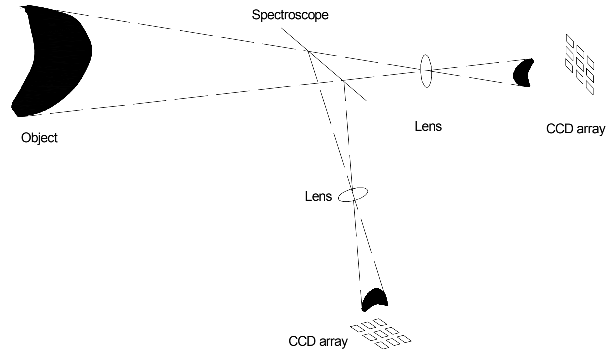

Figure 2. **SR** CCD camera model

SR CCD camera model is added a spectroscope and a lens at the properly place compared with the traditional CCD camera model. And two detector arrays with the same density are placed in the model of Figure 2. Under the same conditions, the resolution of image produced by the traditional camera is equal to that of two images by the **SR** camera. If the place of spectroscope is strictly proper, the time varying phase between the two lenses makes that the distance between samples are half of one CCD array. So we can obtain two frames produced by the **SR** camera, and the samples of frame 2 fall exactly half way between the samples of frame 1 along the vertically scanned image direction. Figure 3 shows a single line of a continuous picture and the outputs of a vertically scanned image along that line in two different frames. The two frames of sampled data can be combined to give a composite sampled data. After reconstructing the composite data by **SR** technology, we can obtain a image with an effective sampling rate which is twice that of either of the original frames.

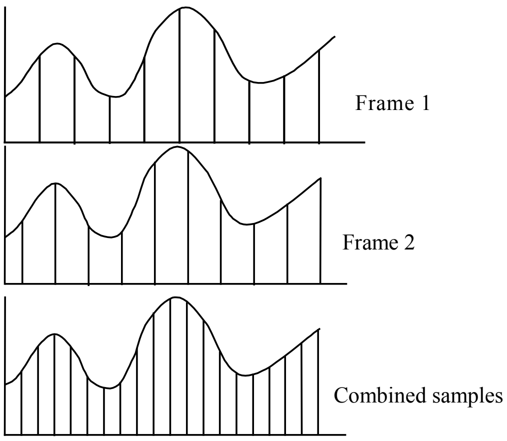

Figure 3. Increasing sample density by combining samples fromtwo different frames produced by SR model

The **SR** CCD camera model in figure 2 is the simulation of HR CCD camera model. It needn't increase the density of detector array while its designment is improved. Composing the **SR** technology in software and the improvement of designment in the CCD camera model, We can get the HR images without more cost and danger. To the generally obtained image sequence with low resolution, figure 4 shows a single line of a continuous picture and the outputs of a vertically scanned image along that line in two different fames. An nonuniformly sampled signal is produced by combining samples from two general frames (Michael, 1988).

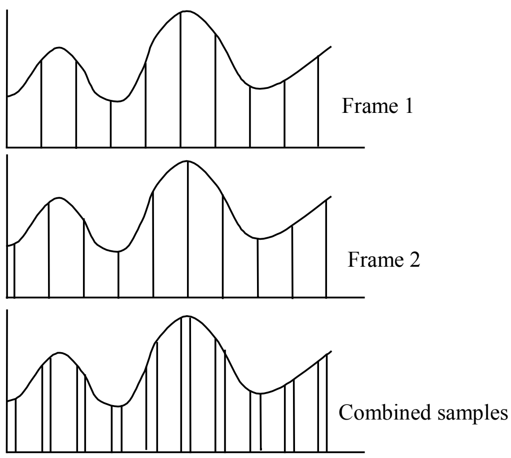

Figure4. Yielding an nonuniformly sampled signal by combining samples generally

After reconstructing nonuniformly sampled signal by **SR** technology, we can obtain a image with a high quality. So the process of **SR** image restoration is shown in figure 5 as follows.

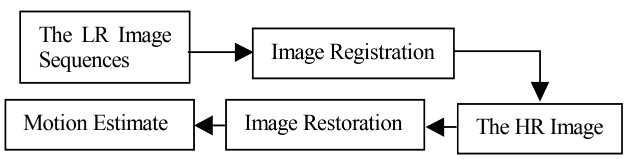

Figure 5. The process of **SR** image restoration

The image registration and the motion estimate are the general signal processing techniques, the more information about them can be consulted in the concerning literatures. The **SR** restoration methods mentioned above can be solved the key question of image restoration.

4. EXPERIMENTAL RESULTS

Two classes of image data are used in the experiments. The one class of data are the LR sequence from a HR **RS** image by simulating the **SR** CCD camera model. This class of data are very ideal relative to the images produced by the real **RS** technology. They fully satisfy the **SR** restoration mechanism. The other class of data are the close-range image sequence, and they are real image data. The following experiments attempt to obtain the images whose resolution is 1 times higher than the undersampled frames.

4.1 Experimental Results of Simulated Data

First discusses how to simulate the LR data from HR image. There is a HR SPOT image with SongShan scene. Its size is 128 ×128 pixels. This array (128×128) is interpolated to obtain a (256×256) array by appending zeros in the DFT domain and then taking the inverse DFT. This procedure is illustrated in figure.6. The image is resampled to obtain several LR frames.

These LR frames needn't registration. And by arbitrarily adopting one of them to be the reference frame, the remaining ones will have different relative shifts with respect to it.

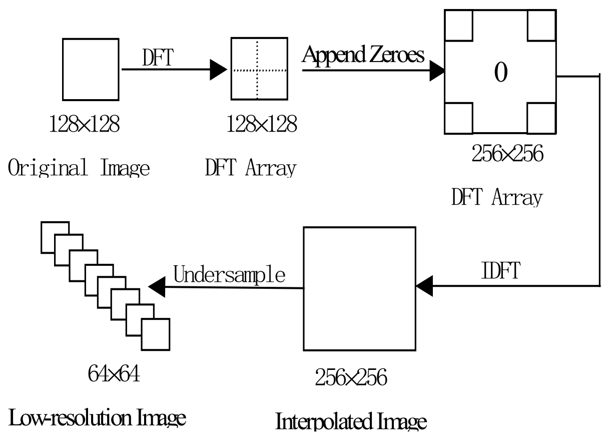

Figure 6. The process of simulation of low-resolution data

The results of simulated data are shown in figure 7. And (a) represents the low-resolution image sequence, (b) represents the image of bilinear-interpolated one of the low-resolution image sequence, (c) the restored high-resolution image from the low-resolution frames, (d) photographed high-resolution image. They have the same meanings in figure 7 and figure 8. We can get approving intention. The restored HR image from the LR frames is of the same resolution as the original HR image, and twice that of any one of LR images.

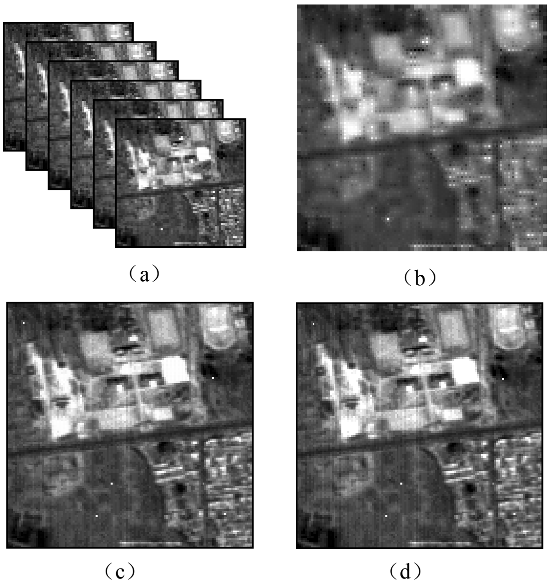

Figure 7. The restoration results of simulated data

4.2 Experiment Results of Close-range Images

Such undersampled frames are photographed by close-range photogrametry. At same time one HR frame is photographed with 2 times resolution as undersampled frames. There are two groups of close-range images to be restored. One group data of close-range image are the text images. Other group data of close-range image are the **RS** photographs. The 8 frames are respectively obtained with same area, and they are registered. So there are only slight shifts and rotations between these images. After motion estimate and reconstruction, the results are shown in figure 8 and figure 9. We can get almost the same approving intention as the test 1. The restored HR image from the LR frames is of the same resolution as the original HR image, and twice that of any one of LR images.

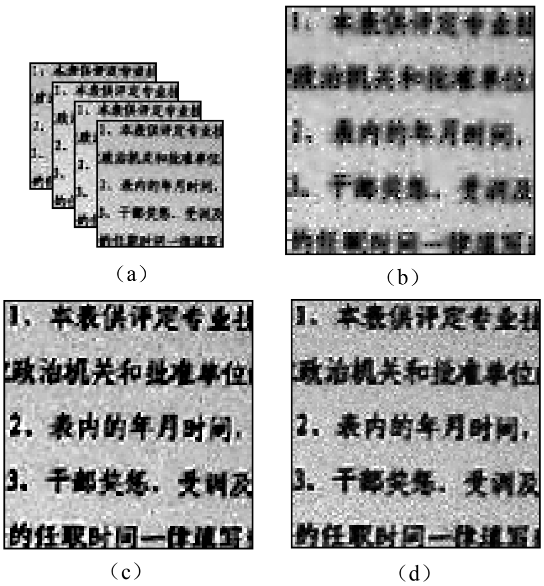

Figure 8. The test results of text images

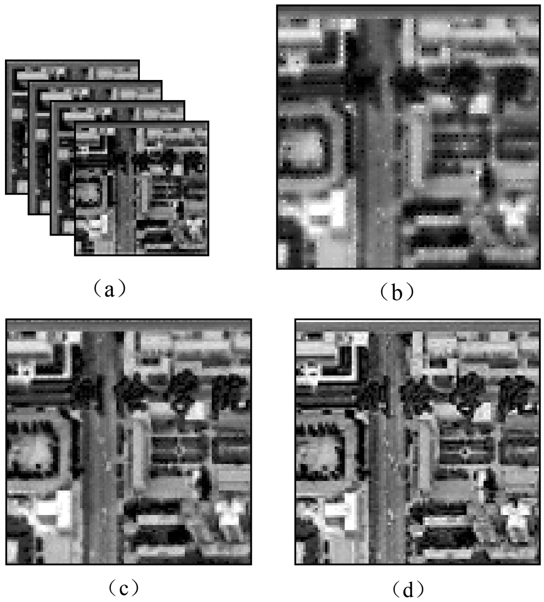

Figure 9. The test results of **RS** images

5. CONCLUSION AND PROSPECT

5.1 Conclusion

SR image restoration is feasible not only in theoretical principle, but also in practical application. **SR** technology can make the obtained LR images of **RS** get the needed precision of discrimination. Consequently these data such as multi-platform, multi-sensor, multi-phase, multi-spectral images of **RS**, together their potentiality can be made full use of. If **SR** CCD camera model such as the improved camera model on the satellite platform is put to use, together with **SR** techniques in software, the images of **RS** will take a new look with the higher resolution. And this imaging system possesses the following superiorities.

1) With the limitation of density of CCD array, improve the spatial resolution of image without changing the optical system;
2) Enhance the reliability of imaging system with two circuit systems;
3) Obtain the high resolution without increasing cost and danger.

5.2 Prospect

SR technology can improve the image spatial resolution efficiently, hence it will be widely used in the many fields. In the **RS** the research of **SR** for the multichannel images will be paid more attention to. This is a development current.

After analyzing and researching the techniques of **SR** image restoration, we can forecast that the work in this field will be developed in the future as follows.

1) Global and local motion estimate techniques with high precision;
2) Degradation models;
3) Restoration algorithms based on probability and set theory.

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