Dynamic Data Updating Algorithm for Image Superresolution Reconstruction

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ABSTRACT A dynamic data updating algorithm for image superresolution is proposed. On the basis of Delaunay triangulation and its local updating property, this algorithm can update the changed region directly under the circumstances that only a part of the source images has been changed. For its high efficiency and adaptability, this algorithm can serve as a fast algorithm for image superresolution reconstruction.

KEYWORDS image superresolution; image interpolation; image registration; Delaunay triangulation

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Introduction

Image superresolution (SR) refers to image processing algorithms which can produce high quality, high-resolution (HR) images from a set of low quality, low-resolution (LR) images through fully exploiting the great potentials of current image data, such as the multi-looked, multi-temporal, multi-platform and sequence images. Considering the additional temporal data available in the image sequence, image superresolution can be more generally considered as a procedure of transferring the temporal bandwidth information to spatial resolution. The SR reconstruction techniques is generally categorized into two classes, the frequency domain approaches and the spatial domain approaches[1,2]. As an important spatial reconstruction approach, SR interpolation reconstruction method is widely used in practical applications for its simple principle and easy implementation properties. Interpolation reconstruction approach can best utilize the inner structures and rules peculiar to LR images sampling grids. From the viewpoint of image sampling, although each frame is sampled on a rectangular grid, but when considering all the LR frames together in a HR grid, they are irregularly sampled and all LR images equal to a non-uniformly sampled data set. The task of image SR reconstruction is to create uniformly sampled images with higher resolution and better quality from this non-uniformly sampled data set. Sauer and Allebach[3] were the first to consider superresolution as an interpolation method for non-uniformly sampled data, then Tekalp et al. [4] extended these algorithms to include blurring and sensor noise and proposed the additional restoration step. But all these approaches still have some shortcomings. All these experiments are aimed at processing synthetically generated test data or video sequence data, no progress has gained in the SR reconstruction of real remote sensing images. Moreover, there is a high demand on the LR images amount that the number of the LR images should be no less than the square of the enhancement factor as to avoid the ill-posed inversion problem during reconstruction. Further, these approaches lack the local updating property that means they can not update the reconstruction result directly when the target data sources chan-
ges and is not applicable for fast processing of image SR reconstruction.

1 Regular Delaunay SR reconstruction algorithm

The constructing character of Delaunay triangulation determines its local updating property, it means if a new point added into the triangulation or a old point deleted from the triangulation, only the related partial triangulation region to the point is influenced and the structure property of the remained region keeps unchanged.

In Delaunay SR reconstruction, interpolation of high resolution grids on the HR image is a specially key problem, it involves the efficiency and adaptability of the algorithm. In order to avoid solving the complex equation sets in interpolation process, a simple and practical image interpolation algorithm based on the "least curve" principle of finite facet is adopted to overcome the ill-posed inversion problem in interpolation reconstruction.

The interpolation technique based on Delaunay triangulation has been widely used in geological field, but it is Lertrattanapanich who first put it into image SR reconstruction application. The fundamental idea of Delaunay triangulation in image SR reconstruction is as follows. Firstly a reference frame is picked out from the LR image, and then other left LR images are precisely registered against the reference frame to generate a non-uniformly sampled discrete data set, and Delaunay triangulation is constructed on the data set subsequently, finally interpolation is carried out on the Delaunay triangulation to convert non-uniform grids into HR uniform grids and realize image SR reconstruction. The Delaunay construction and interpolation algorithm described beforehand is the basics for Delaunay SR interpolation and reconstruction algorithm.

We suppose that there are \( P \) LR frames and each frame is an image of \( N_1 \times N_2 \) size and the resolution enhancement factor is \( r \), correspondingly, the HR grids is an image of \( rN_1 \times rN_2 \) size. The general procedure of interpolation algorithm can be summarized as follows.

1) Choose a reference frame from the LR image, and register all the other LR images against the reference frame into HR sampled grids.
2) Construct Delaunay triangulation from the non-uniformly sampled point in the HR girds.
3) Compute the normal vector for each triangle in the Delaunay triangulation.
4) Set the horizontal and vertical enhancement factor \( r \), and calculate pixel value for each sample grid in the HR image according to Delaunay triangulation, and construct the original HR image using the interpolation method described above.

2 Dynamic data updating algorithm based on Delaunay triangulation

It is a problem encountered commonly in the real application that after the reconstruction having been finished with available data users may want to update the reconstruction with new data, such as acquisition of new image data with time passing on. If all available LR images, including both the used images and the newly acquisitions, are used again in the reconstruction, the high complexity in the computation process will surely lower the efficiency of the interpolation reconstruction.

If we consider the data updating problem in viewpoint of interpolation, we can treat adding new LR image data to current LR data as adding extra pixels into the spatial corresponding relation between LR image and HR grid and the effect of such operation is only restricted in its influential polygons. In this paper we make improvement on the Delaunay SR interpolation and reconstruction algorithm presented in Reference [6], and propose a dynamic updating algorithm based on the local updating property of Delaunay triangulation. The fundamental procedures of the algorithm is illustrated in Fig. 1. The updating reconstruction is a iterative interpolation and updating process. Firstly, the initial HR image is constructed with the common Delaunay triangulation SR reconstruction, and then newly acquired updating images are registered against
the HR image to ascertain their pixel positions in the HR image, and sequentially newly added LR image data are interpolated into the initial Delaunay triangulation to obtain the updated Delaunay triangulation according to the local updating property of Delaunay triangulation. After all updating pixels inserted into the initial Delaunay triangulation, the interpolation is performed on the updated Delaunay triangulation to realize updating the initial HR image and get the updated HR image. The image SR reconstruction efficiency is greatly enhanced because there is no need to construct the new Delaunay triangulation absolutely over again and the newly added pixels can be used to update the reconstruction result on the basis of the initial Delaunay triangulation in fully utilizing the local updating property of Delaunay triangulation. Moreover, the updating algorithm is applicable not only to the situation of adding more pixels to the reconstruction result, but also to the situation of deleting partial pixels from the initial Delaunay triangulation, for example, some badly degraded pixels of the LR images needed to deleted during the reconstruction process to enhance the robustness of reconstruction process.

![Flow chart for Delaunay-based dynamic data updating](image)

**Fig. 1** Flow chart for Delaunay-based dynamic data updating

### 3 Result and analysis

Fig. 2 is the SR reconstruction test result for simulation images. In simulation test, eight LR images were generated using the affine transform model, and the first frame is treated as the reference frame, and all the others sampled pixels were registered into the HR grids on the basis of the first frame. The enhancement factors along both the horizontal direction and the vertical direction are assumed to be 4. Aimed at the simulation test images, MSE (mean square error) index is adopted to access the reconstruction result. In Fig. 2 a comparison is made among the Delaunay iteration and interpolation SR reconstruction result. Fig. 2(a) is the bilinear interpolation result for original LR image, with its MSE index being 98.98, Fig. 2(b) is the initial HR image constructed by the first five LR images, MSE being 32.99, Fig. 2(c) is the updating result of initial HR image with the remainder LR images, MSE being 19.87, Fig. 2(d) is the original HR image. Experimental result proves that the reconstructed image gets a significant improvement from both the visual effect and the quantitative index.

Fig. 3 is the SR reconstruction result using 8
frames of SPOT 4 images. The image size of each frame is $128 \times 128$ and the enhancement factor is 2. Fig. 3(a) is the bilinear interpolation result for original LR image. Fig. 3(b) is the initial HR image constructed by the first five LR images. Fig. 3(c) is the updating result of initial HR image with the other LR images. Experimental result proves that the SR reconstruction algorithm proposed in this paper can also gain a significant reconstruction result in actual remote sensing images.

In order to highlight the efficiency of this algorithm, a comparison between the Delaunay dynamic updating algorithm and the Delaunay regular algorithm based on the above experiment result is made and the comparison result is given in Table 1. It can be seen from the table that it takes the regular reconstruction algorithm 6.6 s and 137.1 s respectively during reconstruction with 8 frames, and that for updating reconstruction algorithm, the initial reconstruction time plus the updating time, is 7.3 s and 150.9 s respectively. It means the updating algorithm has no priority if the reconstruction process is performed over again with the whole LR images. But the updating time is just 2.4 s and 52.4 s, far below the repeated reconstruction time 6.6 s and 137.1 s, when just data change is considered. The proposed algorithm has its greatest advantage over data dynamic updating. The image reconstruction efficiency is greatly improved if only the changed data region is involved in the triangulation updating and interpolation reconstruction when data set alters. The advantage is more evident when only partial image data alters.

![Fig. 2 HR reconstruction from simulated data](image)

![Fig. 3 HR reconstruction from remote sensing images](image)

| Table 1 | Efficiency of this algorithm compared with traditional algorithms |
|---------|---------------------------------------------------------------|
|         | Regular Delaunay SR algorithm/ms | The algorithm proposed/ms |
|         | Initial 5 frames | Add to 8 frames | Initial 5 frames | Add to 8 frames |
| Simulated data | 4 846 | 6 649 | 4 846 | 2 417 |
| Remote sensing data | 98 467 | 137 146 | 98 467 | 52 391 |
4 Conclusions

Experiment results and analyses prove that the dynamic updating reconstruction proposed in this paper is excellent for its simple principle, flexible applicability, low computation complexity and small resource demand. What is more important is that the algorithm has a local updating property, which enables extra images to be inserted into or bad images to be deleted from the initial HR to enhance the reconstruction result. Additionally, the algorithm is adaptable to parallel computation as only current neighbor pixels are involved in calculating pixel value in HR grid and computation complexity is not influenced by the image size. The algorithm also does not have a distinctive restriction on image account, which avoids the ill-posed inversion problem encountered in other SR reconstruction approaches. Therefore, the algorithm is specially applicable for real time processing of continuous image and has a wide developing potential in practical application.

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