THE TECHNIQUE OF QUASI-LOSSLESS COMPRESSION OF THE REMOTE SENSING IMAGE

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ABSTRACT In this paper, the technique of quasi-lossless compression based on the image restoration is presented. The technique of compression described in the paper includes three steps, namely bit compression, correlation removing and image restoration based on the theory of modulation transfer function (MTF). The quasi-lossless compression comes to a high speed. The quality of the reconstruction image under restoration is up to par of the quasi-lossless with higher compression ratio. The experiments of the TM and SPOT images show that the technique is reasonable and applicable.

1 Introduction

With the rapid development of aerial and space remote sensing technique, the digital camera has been explored, and mapping experiments with this kind of digital images are being processed as the regular mode of areophotogrammetry. On the other hand, the technique of integration of 3S (GPS, RS and GIS) has been applied in many fields successfully and widely discussed. The digital photogrammetry system has been put in actual use as a mature technique. Meanwhile, the information superhighway will be the key technique in the coming 21st century. All these developments mean that the spatial geographical data require multi-level remote sensing image data.

In RS, GIS and DPS (digital photogrammetry system), one of the key techniques is how to deal with the real-time transmitting of huge remote sensing data and how to build image data base.

Thus, the technique research of the remote sensing data compression is a very urgent task.

Normal data encoding technique comes to lossless compression, while the compression ratio only ranges about 2. That can not satisfy the actual requirement. The new developing compression techniques, such as wavelet compression and fractal compression, will reach a high compression ratio, but they belong to degraded compression and need more CPU time. These methods have much localization in the field of the remote sensing compression, so they have not much actual use currently.

In this paper, the technique of quasi-lossless compression based on the image restoration is presented. The technique of compression described in the paper includes three steps, namely bit compression, correlation removing and image restoration based on the theory of modulation transfer function (MTF). The quasi-lossless compression comes to a high speed. The quality of the reconstruction image under restoration is up to par of the quasi-lossless with higher compression ratio. The tests of TM and SPOT remote sensing images show that the average compression ratio is about 4 – 5, the fidelity reaches 0.99 and the peak value signal-noise ratio (PSNR) is over 42. All of these results confirm that the
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2 Image compression

The compression process presented in this paper includes two parts: bit compression and correlation removing. Fig. 1 shows the compression flow.

![Image compression flowchart](image)

The bit slicing of digital image shows that the low bits only include a small quantity of information and they are mostly measure of noise. Thus, deleting the low bits image of two bits can reduce the entropy of the image. Correlation removing can also depress the redundancy of the image. All these processing can increase the compression ratio of the remote sensing image. At the same time, the compression processing is very fast. They are quite suitable to the real-time transmission of the remote sensing image and the establishment of the image database.

2.1 Pretreatment of the image compression

The entropy of the image directly affects the compression ratio of the image (Table 1).

| Image Name | Entropy of Original Image | Entropy of High 6 bits Image | Compression Ratio of 8 bits Image | Compression Ratio of 6 bits Image | Compression Ratio after Correlation Removing |
|------------|---------------------------|-----------------------------|----------------------------------|-----------------------------------|---------------------------------------------|
| T1         | 4.09                      | 2.16                        | 2.56                             | 5.07                              | 5.91                                        |
| T2         | 5.02                      | 3.05                        | 1.97                             | 3.61                              | 4.08                                        |
| T3         | 5.55                      | 3.58                        | 1.78                             | 3.08                              | 3.58                                        |
| T4         | 6.33                      | 4.41                        | 1.55                             | 2.47                              | 2.94                                        |
| T5         | 5.73                      | 3.79                        | 1.75                             | 2.99                              | 3.46                                        |
| PYA        | 5.45                      | 3.48                        | 1.90                             | 3.58                              | 4.01                                        |
| PYB        | 5.70                      | 3.74                        | 2.37                             | 4.57                              | 5.64                                        |
| SP1        | 4.16                      | 2.32                        | 2.38                             | 4.65                              | 5.60                                        |
| SP2        | 4.63                      | 2.75                        | 2.19                             | 4.25                              | 5.60                                        |
| SP3        | 4.96                      | 3.02                        | 2.26                             | 4.40                              | 5.08                                        |
| NSP1       | 4.20                      | 2.26                        | 2.63                             | 5.13                              | 6.29                                        |
| NSP2       | 4.85                      | 2.90                        | 2.31                             | 4.48                              | 5.39                                        |
| NSP3       | 5.38                      | 3.42                        | 2.03                             | 3.72                              | 4.35                                        |

If the entropy of the original image is 4 ~ 5, the compression ratio is over 5. If the entropy is 5 ~ 6, the compression ratio is over 3.5. In order to increase the efficiency and the compression ratio, reducing the entropy of the image must be done. The pretreatment of the image compression is to delete the low bits image of two bits.

2.2 Correlation removing of the image

Because of the position adjacency and the coherence of the ground object classification, the gray information of the image has strong correlation in 4-neighborhood or 8-neighborhood of the image. The correlation removing process of the neighboring pixels can depress the image's redundancy further and increase the compression ratio. The integer orthogonal wavelet transformation is done to remove correlation combining the contour feature of the 4-neighborhood or 8-neighborhood.

2.3 Huffman code

In order to ensure the request of quasi-lossless compression, Huffman code without loss is adopted. Huffman code is very fast and its efficiency is considerable. On the other hand, relating to the entropy of the image, lossless compression has a limit. Huffman code can obtain the ratio near the top ratio and be processed easily.

3 Image restoration

As the compression technique discussed in this paper try to cut low bits image of two bits to increase the compression ratio, the quality of the reconstruction image falls down. In order to improve the quality of the restoration image, restoration
processing of the deleted low bits image must be done through the reconstruction image.

3.1 Design of image restoration technique

It is well known that the quality of the remote image is affected by many environment factors, such as image shift and shaking of the sensor platform. These all make the quality of remote sensing images fall down sharply. While the course of falling down of images' quality is random, it cannot be expressed with a fixed mathematical model. Most scholars take the predigested mode when they study the image restoration[14]. For example, they predigest two dimensions point spread function to one dimension line spread function. In addition, they take the imaging system as a space invariable linear system so that the line spread function can be assumed Gauss symmetrical distribution. The image after bit compression can be looked upon as the image with the falling of quality after a high frequency filtering. The principle of image restoration technique is based on the following three premises.

1) Imaging system is a space invariable linear system and then the line spread function of the imaging system is assumed Gauss symmetrical distribution. Then we get:

\[ A(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2}{2\sigma^2}} \]  

(1)

2) According to the hypothesis of Eq. (1), the line spread function \( A(x) \) of the imaging system is shown in Fig. 2:

\[ a', a_1, a_2 \]

(a) The line spread function

3.2 Obtaining of the line spread function \( A(x) \)

From Eqs. (5) and (9), calculating the two eigenvalue \( a_1, a_2 \) of the line spread function \( A(x) \) is the key technique of image restoration so that we can take transformation pixel by pixel to build restoration image. The technique flow of image processing of the deleted low bits image must be done through the reconstruction image.

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Then, according to the principle of imaging, the grey of any pixel is:

\[ g(i) = \begin{pmatrix} f(i-2) \\ f(i-1) \\ f(i) \\ f(i+1) \\ f(i+2) \end{pmatrix} \]  

(2)

In Eq. (2), \( f(i-2), f(i-1), f(i), f(i+1), f(i+2) \) are the grey of the original image. And \( a', a_1, a_2 \) are the numerical values of the line spread function at the neighboring pixels, which are equal to the weight of convolutional imaging.

Considering the line spread function \( A(x) \) as an even function \( a', a_1, a_2 \), and taking negative in the processing of contrary filtering[11], we get

\[ a_1 = a'_1 = -A(\pm 1) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}} \]  

(3)

\[ a_2 = a'_2 = -A(\pm 2) = -\frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}} \]  

(4)

Then, we obtain

\[ g(i) = a_1(f(i-1) + f(i+1)) + f(i) + a_2(f(i-2) + f(i+2)) \]  

(5)

3) Assume that the relation of object function \( f(i) \) and image function \( g(i) \) are linear, that is

\[ f(i) = k(i) \times g(i) \]  

(6)

In addition,

\[ \frac{k(i+2)}{k(i)} = \frac{g(i+2)}{g(i)} \]  

(7)

\[ \frac{k(i+1)}{k(i)} = \frac{g(i+1)}{g(i)} \]  

(8)

Put Eqs. (6), (7), (8) into Eq. (5), we can get Eq. (9):

\[ k(i) = \frac{g(i)}{a_2 \times \left( \frac{g(i-2)^2}{g(i)} + \frac{g(i+2)^2}{g(i)} \right) + \frac{g(i)}{a_1 \times \left( \frac{g(i-1)^2}{g(i)} + \frac{g(i+1)^2}{g(i)} \right) + g(i)} \]  

(9)

So we can get the original image pixel by pixel through Eqs. (5) and (9). This is the restoration processing.

3.2 Obtaining of the line spread function \( A(x) \)

From Eqs. (5) and (9), calculating the two eigenvalue \( a_1, a_2 \) of the line spread function \( A(x) \) is the key technique of image restoration so that we can take transformation pixel by pixel to build restoration image. The technique flow of image
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The process of image reconstruction & restoration

In order to get $a_1, a_2$ from Eqs. (1), (3) and (4), $\sigma$ must be calculated at first. The following is the detailed process$^{[1]}$:

1) Searching the straight edge in the image according to row and column separately and taking the following cosine curve formula to simulate the edge curve based on the approximate sampling value of the edge curve.

$$H(x) = A \cos Bx + C \quad (10)$$

In the Eq. (10), $x$ stands for the coordinate of pixel; $H(x)$ is the grey of pixel. Thus, at least three pairs of $(x, H(x))$ are needed to work out $A, B$ and $C$. The pivotal question is how to pick up three or more pairs of $(x, H(x))$. Edge feature in digital image is continuous pixels with the grey increasing or decreasing by degrees. Thus we draw out feature edge according to some orderliness from the whole image. Synthesizing the feature values and taking them as the initial value of Eq. (10), the edge curve can be simulated quickly. The characteristic of this method to simulate the edge curve is that it does not have to find obvious edge in the image.

As a complete unit of the image restoration, the calculation method of the edge curve is approximate, while it has self-adaptability according to the theory to pick up the edge curve.

2) The solution of the line spread function

The slope of every point in the edge curve $H(x)$ distributed as the brightness is the value of the line spread function.

$$A(x) = \frac{\partial H}{\partial x} \quad (11)$$

Calculating differential coefficient point by point in the edge curve can obtain the line spread function. The restoration presented in this paper is based on the following two points. First, the imaging system is a linear system for position invariance in the spatial domain. Secondly, the line spread function is a Gauss distribution. From Eqs. (1) and (11), we get

$$H(x) = \frac{1}{\sqrt{2\pi} \sigma} \int_{-\infty}^{+\infty} e^{-\frac{x^2}{2\sigma^2}} \, dx \quad (12)$$

Thus,

$$H(\sigma) = 0.16 \quad (13)$$
$$H(-\sigma) = 0.84 \quad (14)$$

This is showed in Fig. 4.

3) Thus, $\sigma$ can be obtained from Eqs. (12), (13), (14). That is,

$$\sigma = \frac{1}{2} \left[ \cos^{-1} \left( \frac{C - 0.16}{A} \right) - \cos^{-1} \left( \frac{C - 0.84}{A} \right) \right] \quad (15)$$

According to Eqs. (3), (4) and (15), we can get $a_1, a_2$. For $a_1, a_2$ are negative, $k$, is not less than 1.0. This might compensate the deleted low bits image of two bits. Thus, the whole restoration process can be described as follows. First, calculate the line spread function and $a_1, a_2$ from the reconstruction image (6 bits). Secondly, obtain the coefficient $k$. Then, do the transformation (Eq. (8)) pixel by pixel to get 8 bits image. At last, add the low bits image of two bits, which is drawn out from the 8 bits image in the previous step, to the reconstruction image. The whole restoration process has been shown in Fig. 3.
In order to prove that the restoration processing has compensated the low bits image of two bits, some statistic value of the low bits image of two bits between the original image and the restoration image are calculated. Table 2 is the statistic result:

| Image Name | Max  | Min  | Aver | Entropy | Deviation |
|------------|------|------|------|---------|-----------|
| NNL        | 3/3  | 0.41 | 1.50 | 2.00    | 1.14      |
| NNL        | 3/3  | 0.41 | 1.53 | 2.00    | 1.12      |
| NNL        | 3/3  | 0.41 | 1.40 | 2.00    | 1.12      |
| NNL        | 3/3  | 0.41 | 1.38 | 2.00    | 1.11      |
| NNL        | 3/3  | 0.41 | 1.23 | 1.98    | 1.10      |
| NNL        | 3/3  | 0.41 | 1.34 | 1.99    | 1.10      |
| NNL        | 3/3  | 0.41 | 1.12 | 1.99    | 1.10      |
| NNL        | 3/3  | 0.41 | 1.10 | 1.99    | 1.10      |

The statistic result is basically accordant. It shows the restoration method is correct.

4 Experiments and quality appraisal

A compression and restoration system of remote sensing image based on the technique of quasi-lossless compression was designed. The system includes four parts: image compression, image reconstruction, image restoration and image quality check. All these are shown in Fig. 5.

![Fig. 5 The quasi-lossless compression system](image)

The compression test results of 5 TM images and 8 SPOT images show that the compression ratio (Table 1) and the images quality after restoration (Table 4) both increase.

Table 3 is the test images in this paper.

| Image Name | Sensor | Experiment Area | Image Size (Pixels) |
|------------|--------|----------------|--------------------|
| T          | Landsat (America) | Suburb of Wuhan | 512 × 512 |
| PYA        | SPOT (France)      | Urban Area of Beijing | 6 000 × 6 000 |
| PYB        | SPOT (France)      | Suburb of Beijing   | 5 000 × 5 000 |
| SP         | SPOT (France)      | Wuhan City (1986)  | 500 × 500 |
| NSP1       | SPOT (France)      | Wuhan City (1995)  | 1 024 × 1 024 |
| NSP2       | SPOT (France)      | Wuhan City (1995)  | 1 024 × 1 024 |

In the digital image communication, fidelity and PSNR are often taken to do the quality access of reconstruction images. The calculation formulae are:

\[
FIDELITY = \sum_{j=1}^{n} g(j)' \times g(j) / \sum_{j=1}^{n} g(j) \times g(j) \quad (16)
\]

\[
PSNR = 10 \log \left( \frac{255^2}{\delta} \right)^2 = 48 - 20 \log \delta \quad (17)
\]

In Eqs. (16) and (17), \( g(j)' \) is the pixel grey of the original image; \( g(j) \) is the pixel grey of the reconstruction image; \( n \) is number of image pixel;

\[
\delta = \sqrt{\frac{\sum_{j=1}^{n} (g(j) - g(j)')^2}{n}}
\]

Fidelity is the geometry distortion of the reconstruction image compared with the original image. PSNR is the radiation distortion of the reconstruction compared with the original image. Obviously, if the image has no loss, the fidelity is 1.0 and PSNR is infinity (expressed as \( \delta = 0 \)). If \( \delta \) equals to 1.0, PSNR is 48. If \( \delta \) equals to 2.0, PSNR is 42. The quality request of the quasi-lossless compression comes from the standard above 2.0. Table 4 is the quality of restoration image.

From Table 4, the quality of restoration images has a large-scale improvement. The test results show the technique of the quasi-lossless compression in this paper is reasonable. For example, Fig. 6(a) is the original image of T4. Fig. 6 (b) is the reconstruction under restoration image of T4.
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(a) The original image
(b) The restored image

Fig. 6 Compare of the original image and restored image

Table 4 Comparison between reconstruction images and restoration images

| Image Name | Reconstruction Images (FIDELITY/PSNR) | Restoration Images (FIDELITY/PSNR) |
|------------|---------------------------------------|------------------------------------|
| T1         | 0.953 3/42.55                        | 0.999 2/46.11                      |
| T2         | 0.956 2/41.83                        | 0.998 4/44.52                      |
| T3         | 0.974 4/40.93                        | 0.998 7/42.87                      |
| T4         | 0.979 0/39.41                        | 0.998 3/40.77                      |
| T5         | 0.957 8/41.34                        | 0.997 6/43.56                      |
| PYA        | 0.973 3/41.73                        | 0.998 4/43.57                      |
| PYB        | 0.982 4/42.30                        | 0.999 9/45.35                      |
| SP1        | 0.967 7/42.27                        | 0.998 7/44.87                      |
| SP2        | 0.960 5/41.89                        | 0.999 4/44.38                      |
| SP3        | 0.954 6/42.16                        | 0.999 4/45.03                      |
| NSP1       | 0.967 4/42.25                        | 0.996 9/45.93                      |
| NSP2       | 0.968 8/42.29                        | 0.998 2/45.53                      |
| NSP3       | 0.958 7/41.71                        | 0.998 1/44.38                      |

5 Conclusions

In this paper, the technique of the quasi-lossless compression based on the image restoration is presented. After restoration processing, the fidelities of compression images are all over 0.99. PSNR proves separately, such as 2.35 (T), 2.44 (PY), 2.65 (SP) and 3.19 (NSP). All PSNR are over 42 except T4 while its entropy is too high (6.33). The experiment also shows that the technique of the quasi-lossless compression is quite fit for the RS images. This technique can not only be used in Digital Photogrammetry System (DPS) and Image Database, but also provide a new technique approach in the research of RS images' real-time transmission.

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