PROPERTY AND REMOVAL OF JITTER IN BEIJING-1 SMALL SATELLITE PANCHROMATIC IMAGES

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ABSTRACT:

Attitude of the Small satellite is prone to be affected by external disturbing factors due to its small inertia. As for Beijing-1 small satellite, jitter is induced and exhibited in the images taken while the outside disturbance is intense. The jitter is manifested as jagged lines and edges in the images, leading to distortion of geometric property of the objects. In this paper, properties of the Beijing-1 small satellite jitter are explored based on analyses of affections of attitude jitter with diverse frequency and directions to the imaging process. Accordingly an image based jitter removal method is brought up, the proposed method removes jitter effectively and can be introduced into practical production process.

1. INTRODUCTION

Small satellite has gained universal attention due to remarkable advantages including flexibility and low cost, and has become a trend for developing of future satellites. However, owning to massive application of lightweight materials, inertia of the small satellite is greatly reduced, leading to low attitude stability and frequent imaging errors.

Beijing-1 small satellite was launched into the space as a member of the Disaster Monitoring Constellation in October 2005. The panchromatic sensor onboard has 4-meter resolution and 24-kilometer swath. Till now, images acquired from the satellite have been widely used in agriculture, hydrology, city planning, relic protection, 2008 Olympic Game related observation and many others. However, at times when the attitude is quite unstable, the satellite trembles and causes jitter of the onboard camera, thus leading to abnormality of the acquired images. Analyses have been done on exploring disciplinarian of the jitter and its affections on the imaging process[1-5], however, few researches has been done on manifestation and removal of the jittered images. In this paper, manifestation and regulation of the jitter in images is explored and research on removal of the jitter is conducted.

2. JITTER AFFECTIONS ON IMAGING PROCESS

During the on-orbit operation of the satellite, any motivation of the components can cause jitter response of the camera. When attitude of the satellite is disturbed, the attitude compensation module is motivated. In this course, mechanical movement of the apparatus and activation of electronical system may lead to jitter, even resonance, of the camera. In operation, the jitter is stochastic, it can be of various frequency and directions and have diverse affections on the imaging process.

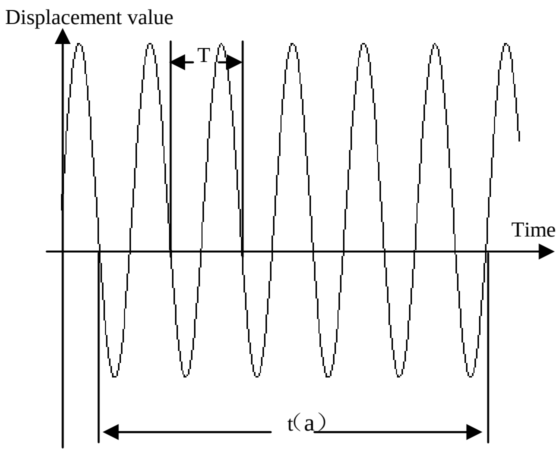
2.1 Affections of Jitter with Different Frequency

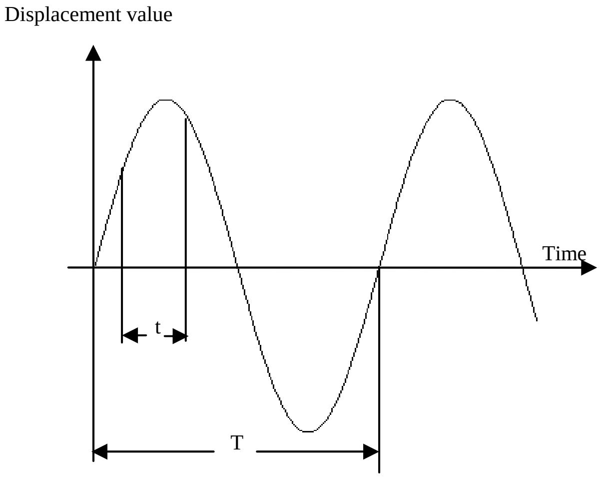
Jitter of any kind can be decomposed into a series of sine and cosine waves. Therefore the analyses below are based on consideration of simple sine waves.

Quality reduction status of jittered image varies with the ratio of integration time t and T, where T represents period of the jitter.

If t is larger than T, the jitter is called high frequency jitter. One or more jitter cycles are present during the integration time, the high frequency jitter expands diameter of the blur circle and causes blurring of the image (Figure 1(a)).

If t is smaller than T, the jitter is called low frequency jitter. In this case, the jitter can be taken as linear movement added to the imaging process. Motion of the blur circle causes degradation of the image. Displacement of every blur circle is decided by the place of pixel integration time on the jitter wave. The value fluctuates in certain ranges. If swing of the jitter is rather large, so is the displacement value, the pixel is likely to be deviated from the original place (Figure 1(b)).





(b)

Figure 1. Affection of different frequency jitter on imaging process, where (a) represents high frequency jitter with t > T, (b) represents low frequency jitter when t < T

2.2 Affections of Jitter with Different Directions

Satellite jitter can be separated into three directions, along optic axis, along track and across track. Here image quality affections of jitter in different directions are discussed.

When the jitter is along optical axis, change of the blur circle diameter *d* can be expressed as

$$d = \frac{Df}{H - f - a} \tag{1}$$

Where f = focal length
H = height of the orbit
a = swing of the jitter wave
D = aperture of the camera

For jitter along track, the equation is as follows.

$$d = c + vt = c + \frac{f}{H} . \frac{a}{T/4} .t \tag{2}$$

Where v = motion speed of the imaged objects. Jitter in along track direction mainly changes v value and disturbs the imaging process.

For the fact that in satellite imaging process, H is far larger than f, the change of d is inapparent, along optical axis and along track jitter has little impact on quality of the acquired images.

Jitter across track causes diameter expansion of the blur circle, if swing of the jitter is large to some extent, pointing object of the CCD sensor will change and cause geometric errors in imaging process. Affection of across track jitter can be devastating and is the most remarkable.

3. PROPERTIES OF BEIJING-1 SMALL SATELLITE JITTER

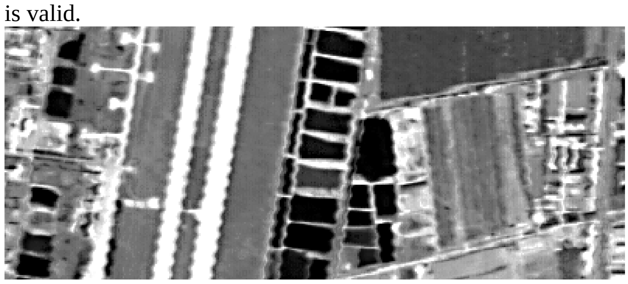
To facilitate exploration of jitter characteristics, data employed in our research is the Level 1 product with radiometric correction done.

In Beijing-1 small satellite images, jitter performs as jagged edges, period of the jag is about 8 to 9 lines, the frequency approximates 200 HZ. Period of the jitter is not only larger than pixel integration time, but also larger than line integration time. It is low frequency jitter. In visual observation, the jagged edges mainly express the devastating across track jitter, the jitter can be assumed as similar linear movement of pixels on the whole line, which causes displacements of pixels to their original positions and lead to jagged edges and linear objects shown in the image. As period of jitter is far larger than pixel integration time, displacements of pixels on the same line can be taken as one value.

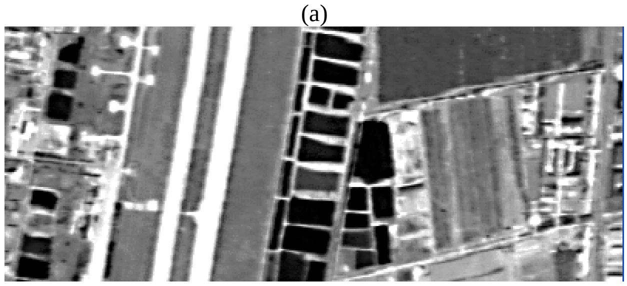
To prove applicability of the above assumptions in jitter removal process, the model is testified with Beijing-1 panchromatic image containing linear objects to see if jitter performance in the image does conform to the hypothesis. As jitter shows clearly on linear objects and edges, the runway from an airdrome is chosen to evaluate property of the jitter. Properties obtained from an airdome are taken as reference for correction of the whole line.

The process is as follows. First, the jittered runway is segmented using proper threshold, then DN centroid of the segmentation result is calculated as central position of the runway, after that, linear regression is done with x y value of the central position and residual value is calculated.

The runway can be restored to be linear by taking the residual as displacement value in horizontal shifting of relevant lines. With applying the displacement value to shifting and sampling of whole lines of the image, jitter that affiliates to all linear objects and edges are removed (Figure 2). Therefore it can be confirmed that the assumption of the jitter in Beijing-1 panchromatic image as uniform displacement of pixels on lines is valid.



(a)



(b)

Figure 2. Jitter evaluation with image of an airdrome, where (a) represents the jittered image, (b) represents the image after shifting and sampling of whole lines

The achieved displacement from the runway is shown in Figure 3, the displacement value ranges from -1 to 1, fluctuates with the disciplinarian similar to that of a sinusoid, except that the frequency and swing is stochastic. Similar conclusion can also be drawn from experiments with other linear objects.

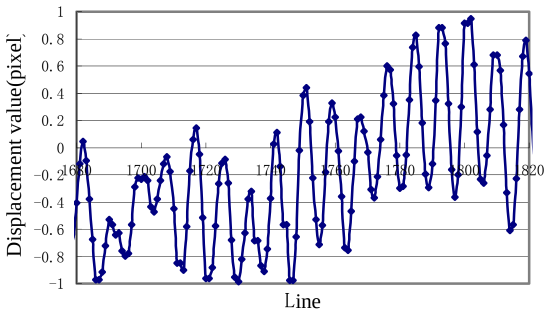


Figure 3. Displacement value of each line

Uniform are displacements of pixels on the same line, manifestation of jitter affiliated to linear objects in different directions varies. Hence line jitter performance with image containing multi-direction linear objects is simulated as validation (Figure 4). Consulting the figure above, period of the jitter is set to be 8.3 lines and swing is assumed to be one pixel. Displacement value of line *i* can be calculated with equation 3.

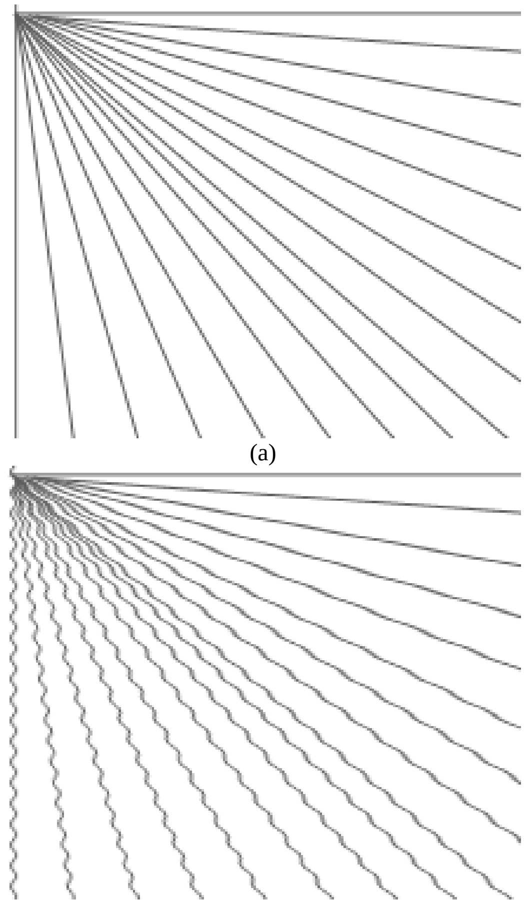
$$l(i) = 1.0 * \sin(\frac{2\pi i}{8.3}) \qquad (3)$$

The simulation result explains the variational performance of jitter on lines with diversified direction. Jitter shows clearly in vertical and near-vertical lines. However, as direction of the line approaches horizontal, displacement of pixels on the line is somewhat compensated by their tendency. Jitter gradually fades away as lines fall horizontal, in horizontal lines jitter can not even be seen visually. Performance of jitter in the simulated image is the same as that in Beijing-1 panchromatic images.

It can be concluded from the above analyses that jitter in the Beijing-1 panchromatic image can be modelled as varied horizontal displacements of the lines. Thus by proper horizontal shifting of the lines, jitter in the image can surely be removed. The key factor lies in proper assessment of the line displacement values.

4. JITTER REMOVAL

The adjacent lines in 4-meter resolution image can be considered as highly correlated due to the high sampling rate. If the lines are shifted, their correlation value degrades. This theory fits the correlation of lines in unjittered Beijing-1 panchromatic image. Figure 5 shows variation of the line correlation values against displacement changes between adjacent unjittered image lines. In the figure, three groups of lines and their correlation variation curves are drawn, showing degraded correlation with increasing displacement while the absolute displacement value is less than 40. It implies that the displacement value can be evaluated by degradation condition of the correlation.



(a)

(b)

Figure 4. Jitter simulation with image containing multi-direction linear objects, where (a) is the original image, (b) is the image acquired with line jitter added

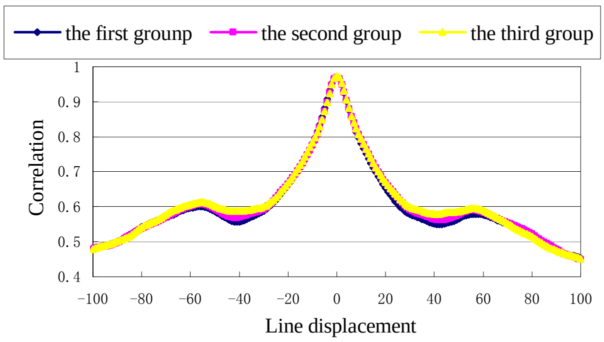


Figure 5. Correlation between unjittered adjacent lines

The jitter in Beijing-1 panchromatic images range from -1 to 1. In this range, the correlation distribution is a one-peak curve. Figure 6 shows correlation variations of nine groups of jittered image lines, the peaks swing from -1 to 1, the displacement values with correlation on the peak can be taken as line displacement values that can be used to rectify the jitter. Therefore, least square fitting of the curves can be used to get the displacement values with the highest correlation.

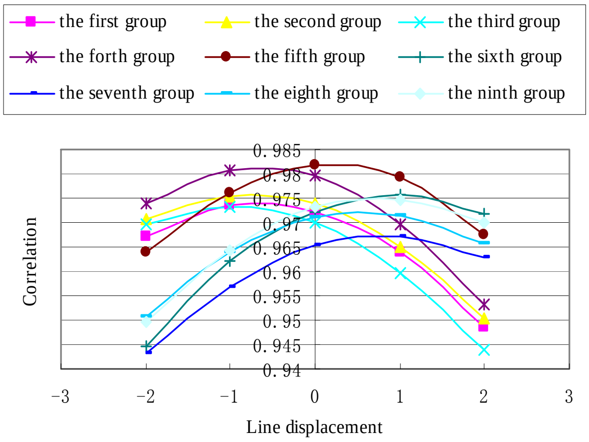


Figure 6. Relation of correlation to line displacement

For the need to conduct small error curve fitting around the peak, the samples used should be in the peak vicinity. So, only five groups of correlation of line *j* and *j*-1 with displacement ranging from -2 to 2 are used in the curve fitting. The groups are fitted to a quadratic curve. The fitted equation and the desired displacement value are as follows.

$$f_j(x_j) = a_j * x_j^2 + b_j * x_j + c_j$$
$$d_j = x_{\max f_j(x_j)} = -b_j / 2 * a_j \qquad (4)$$

To avoid curve fitting errors, the absolute value of acquired d_j is constrained to be smaller than 1, conditioned correction is performed during estimation, the d_j is substituted by displacement of the preceding line d_{j-1} if the value is greater than 1.

As the jitter is modelled to be horizontal shifting caused by deviated observation, the image can be restored by position correction of each pixel, thus horizontal shifting is performed according to d_j, the idea is shown in Figure 7, for simplification, the linear pixel unmixing is adopted, each pixel is considered as linear combination of the original two adjacent pixels.

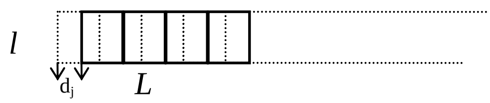


Figure 7. Horizontal sampling

the sampling equation is as follows

$$L(i, j) = d_j * l(i, j) + (1 - d_j) * l(i+1, j) \qquad (5)$$

The whole process of jitter removal is shown in Figure 8.

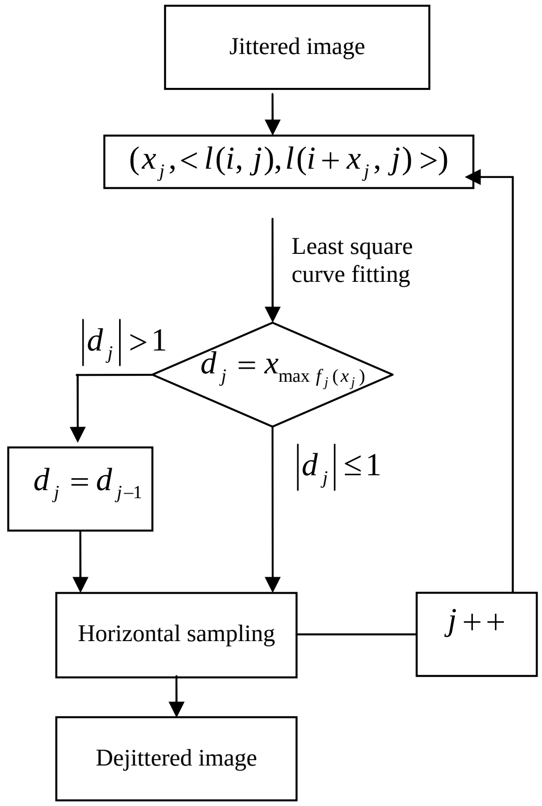


Figure 8. Process of jitter removal

After processing, jitter in the images is removed, shape of the edges are restored. The processed image regains geometric information of the objects and achieves better visual effect. The images before and after processing are shown in Figure 9.

(a)

(b)

Figure 9. Processed results, where (a) is the jittered image, and (b) is the image after dejitter processing

5. CONCLUSIONS

High resolution imaging requires attitude of the satellite to be extraordinarily stable. Small satellite, owning to the small inertia, is hard to keep still under outside disturbance. Usually, extra dumper is fixed onboard to counteract the affection. Even so, jitter that can not be eliminated by the attitude compensation devices still exists. Ground image processing methods have to be resorted to remove the jitter.

For few researches has been done on satellite jitter and its manifestation in images, property of the jitter in Beijing-1 small satellite has to be achieved via assumptions and experiments, thus leading to the solution. The jitter removal method brought up here has been tested with various data sets and is proved to be effective, besides, its adaptiveness in large image treatment and batch processing facilitates the application in industrialized production process.

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