

The Removal of Trembling Artifacts for FORMOSAT-2

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ABSTRACT:

Since the successful launch of FORMOSAT-2 satellite by National Space Organization of Taiwan in May 2004, the Remote Sensing Instrument (RSI) on-board the FORMOSAT-2 has continuously acquired images at one panchromatic and four multi-spectral bands (<http://www.nspo.org.tw>). In general, the RSI performs well and receives high quality images which proved to be very useful for various applications. However, some RSI panchromatic products exhibit obvious trembling artifact that must be removed. Preliminary study reveals that the trembling artifact is caused by the instability of the spacecraft attitude. Though the magnitude of this artifact is actually less than half of a pixel, it affects the applicability of panchromatic products. A procedure removing this artifact is therefore needed for providing image products of consistent quality. Due to the nature of trembling artifact, it is impossible to describe the trembling amount by employing an analytic model. Relied only on image itself, an algorithm determining trembling amount and removing accordingly the trembling artifact is proposed. The algorithm consists of 3 stages. First, a cross-correlation based scheme is used to measure the relative shift between adjacent scan lines. Follows, the trembling amount is estimated from the measured value. For this purpose, the Fourier transform is utilized to characterize random shifts in frequency domain. An adaptive estimation method is then applied to deduce the approximate trembling amount. In the subsequent stage, image re-sampling operation is applied to restore the trembling-free product. Experimental results show that by applying the proposed algorithm, the unpleasant trembling artifact is no longer evident.

Key words: Trembling artifact, Cross correlation, FORMOSAT-2 Image

1. Introduction

The satellite FORMOSAT-2 was launched in May 2004. To meet its mission objectives, the FORMOSAT-2 is equipped with payloads, namely, the ISUAL and the RSI. The ISUAL (Imager of Sprites and Upper Atmospheric Lightning) is used to observe the natural upward lighting discharge phenomenon towardly the ionosphere on the top of the tropopause. The RSI (Remote Sensing Instrument) is used to acquire remote sensing image for nature resources management.

Orbiting on a sun-synchronous orbit of altitude 891 km, the FORMOSAT-2 is renowned for its daily revisiting capability. For given interesting area, the FORMOSAT-2 is superior in providing on a daily basis the image data of consistent geometric and radiometric qualities. Making a good use of this feature, the FORMOSAT-2 will be an invaluable asset for certain remote sensing applications.

The FORMOSAT-2 is an agile platform with capability to steer along and across the track up to 45°. With this agility, the on-board RSI could be programmed to take images of different locations and also to acquire in-orbit stereo-pairs. The RSI performs its job by employing push-broom scanning mechanism. Its spectral modes include one panchromatic (PAN) and four multi-spectral (MS) bands. In nadir-pointing mode, the spatial

resolution of PAN and MS images are 2 m and 8 m respectively, and the swatch is 24 km. At its orbiting altitude, the FORMOSAT-2 takes 3.7 seconds to acquire a scene-worth dataset.

Tons of FORMOSAT-2 RSI images have been collected, archived, and processed in the National Space Organization (NSPO), Taiwan. The majority of pre-processed image products the NSPO provided includes Level 1A and Level 2 products. A level 1A image is a radiometric corrected and geometrically raw product. A level 2 image is a radiometric corrected and cartographic mapped product. In addition to supporting typical research and civil applications, these products are also used intensively in evaluating damage resulted from nature disaster events such as typhoon, flood, and land slide as well as the South Asia Tsunami.

In general, the excellent image quality the FORMOSAT-2 provided serves the foregoing application well. Nonetheless, some FORMOSAT-2 PAN images exhibit certain degree of defect identified as "trembling artifact". For that such a defect may impose some limitations on a number of applications. A procedure releasing the defect is needed. In response to such a need, a trembling removal algorithm is proposed in this work. Experimental results show that by applying the proposed algorithm, the defect is practically removed without essential cost in sense of operational load.

Next section, we describe first the nature of trembling artifact. Follows, we detail in section about the trembling removal algorithm and its implementation considerations. The effectiveness of the proposed algorithm is exemplified in section 4. The last section concludes this work.

2. Trembling artifact

To explain the trembling artifact, a level 1A image with profound trembling artifact is chose as an example in this article. Figure 1 shows this image which was taken on October, 05, 2004 over Valencia, Spain. Subsectioned from this image, a 256×256 close-up patch shown in figure 2. A glance at figure 2, one may notice that some man-made objects present notable wrinkle features along the edges. The term “trembling artifact” or “trembling phenomena” is intuitively used to identify this sort of distortions.

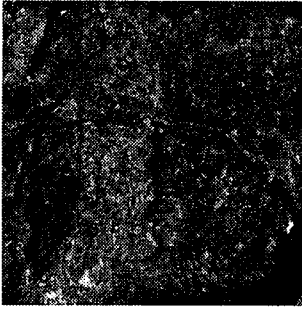


Figure 1 Full scene



Figure 2 Magnified patch

To characterize this distortion, a horizontal slice of figure 1 is closely examined. Through out the slice, we found the distortion is highly consistent. However, such consistency is not observed if we tiny to inspect downward along a vertical slice. Instead, we found the wrinkle patterns do not stick to any clear rule. A preliminary study shows the frequencies of the trembling artifact resemble the jitter character of RSI. It is then appropriate to reason that the defect is resulted from its attitude occurred during the image process. In this expression, the term attitude is used to relate the orientation of image reference frame to the local frame. In a trembling image, the relative offset between adjacent scan lines may then be imagined as a result of a sudden change in roll angle. For FORMOSAT-2, such a sudden change may steer the pointing of RSI deviated from its nominal direction up to 10^{-6} radian.

Though corresponding to trembling-artifact, the distortion is small in magnitude ($\leq 1\text{m}$ on ground surface), it do cause visual barrier. Moreover, it may lead image post-processing into erroneous result. Examples include those applications using 2-D cross-correlation, edge detection, image morphology, etc. To ease the difficulty to be encountered in post-processing phase and also to provide image product of consistent quality, there is a need to develop and implement a trembling removal solution in image pre-processing phase.

3. Algorithm

If somehow we can quantity the relative offset between adjacent lines, we can derive the compensation amount needed for trembling-free image generation. Learnt from our observation, trembling artifact does not adhere to a definite behavior, which makes it merely the only way to quantify the relative offset based on the image itself. Consequently, a 3-stage algorithm is proposed. The first step measures the relative shift between adjacent scan lines. The second stage determines the relative offset based on the measured relative shift and calculate the compensation amount. The final step restores image.

The displacement between two similar 1-D functions can be estimated by applying a cross-correction operation. (Gonzalez and Woods, 2002; Paul, 1996) For detecting the relative displacement between two radiometric corrected images to a sub-pixel accuracy. Chang and others (2004) have developed and validated a scheme which incorporates normalized cross-correlation in operation into a interpolation estimation. (Chang et al., 2004) In our work, we adopted and modified their scheme to measure the relative shift between adjacent scan lines. A simulation is designed to evaluate the accuracy of this measurement. It is found that for our application, the measurement uncertainty is far less than 0.1 pixel.

Determining the relative offset is somewhat subtler, we thus defer the discussion until the next paragraph. Providing with known compensation amount, cubic convolution is a handy image resampling algorithm for our image restoration work. It should be however noted that due to the existence of relative offset, a conventional cubic convolution procedure will not serve our purpose adequately. This is especially true if level 2 product is in request. To ensure a correct operation, additional effort was made to carry out an adaptive convolution kernel.

Let $\Delta y_i(k)$ denote the relative offset between line k and line $k-1$. Also let $\Delta Y_i(l)$ denote the compensation amount to be sued to offset the line l to its nominal position. Presuming $\Delta y_i(k)$ is well known for every k between 2 and l by setting $\Delta Y_i(1)$ to certain value, the compensation amount $\Delta Y_i(l)$ can then be computed using the following equation:

$$\Delta Y_i(l) = \Delta Y_i(l-1) - \Delta y_i(l) = \Delta Y_i(1) - \sum_{k=2}^l \Delta y_i(k) \quad (1)$$

To determine Δy_i needed in this equation, the relative shift Δy between k and $k-1$ is measured using a cross-correlation based scheme which we mentioned earlier. With this scheme, the measurable could be written as:

$$\Delta y(k) = \Delta y_i(k) + \Delta y_g(k) + \Delta y_m(k) \dots\dots\dots (2)$$

where, Δy_m denotes the error resulted from measurement uncertainty, and Δy_g denotes the collective tendency of

surface features with respect to satellite motion. Substitute eq. (2) to eq. (1), the compensation amount $\Delta Y_i(l)$ could be re-written as:

$$\Delta Y_i(l) = \Delta Y_i(l) - \sum_{k=2}^l \Delta y(k) + \sum_{k=2}^l \left(\sum_{k=2}^l \Delta y_g(k) + \Delta y_m(k) \right) \quad (3)$$

Hence, by removing Δy_g and Δy_m , the compensation amount ΔY_i could be deduced from the measured relative shifts Δy . A careless observation at a trembling image may lead one to have an impression that Δy_g and Δy_m in eq. (2) are both insignificant. Besides that the impression may deviate notably from reality, the neglect of these terms actually invites outstanding errors to the compensation amount ΔY_i calculated using eq. (3). A method to single out relative offset Δy_i from measured relative shift Δy is hence needed. Since the relative shift Δy is the only quantity obtainable, we will not try to solve the relative offset Δy_i , instead, we try to estimate it smartly by exploiting the distinguishability between function behaviors.

In this article, we define the relative offset $\Delta y_i(k)$ as the direct outcome of pointing instability. In other words, the function $\Delta y_i(k)$ approaches to certain extent the wrinkle pattern we inspected in the previous section. Judged from what we observed, $\Delta y_i(k)$ is categorized as a fast varying function.

As to the measurement error $\Delta y_m(k)$, our simulation reveals that its behavior mimics a random process. Though the magnitude of this function is quite small, as typified by the famous random walker phenomenon, significant but unpredictable error will be built-up through the accumulation process employed in eq. (3). To prevent the built-up error, this function is decomposed to slow-varying components and fast-varying components. While the slow-varying components favour the built-up error, they should be removed. On the other hand, errors contribute fast-varying components tend to cancel each other in an accumulation process. Furthermore, due to their insignificant magnitude, neglecting them will not cause perceptible trembling artifact in eq. (2). Accordingly, fast-varying components may be left if they are inseparable from relative offset $\Delta y_i(k)$.

For the collective tendency, one may expect that lied on the imaged area, ground objects distribute randomly and each individual object takes its own orientation. Thus, the function $\Delta y_g(k)$ should be small in magnitude. Often, this is not far from the fact for certain type of target area characterized by the uniform features. If this happens to be the case, $\Delta y_g(k)$ can simply be treated as $\Delta y_m(k)$. For other type of target area characterized by geometric structures, further analysis is needed. Frequently, the presence of substantial target

dominates more or less the distribution of near-by objects and sometimes even aligns their orientations. Such cases can be exemplified by the mountains and rivers as well as major buildings and well-planned cities. Due to the scale of these dominate target, the collective tendency usually possesses important slow-varying components. As to the fast-varying components, while the contribution from the influence of a single dominant target is not negligible, the presence of multiple dominant targets usually tends to weaken its importance. Precaution should be noticed however for certain exception. A strong and elongated edge orientated in near horizontal direction causes $\Delta y_g(k)$ an abrupt change, therefore, the fast-varying part of the collective tendency can not be neglected. Even worse, such a feature may fail the scheme detecting relative shift.

In summary, the relative offset $\Delta y_g(k)$ responsible for trembling artifact composes mainly the fast-varying components. Save few exceptions, the slow-varying components dominate the measurement error $\Delta y_m(k)$ and the collective tendency $\Delta y_g(k)$. Therefore it is possible to find a good estimation of the relative offset $\Delta y_i(k)$ by extracting from the relative shift $\Delta y(k)$ the fast-varying components.

Among various possibilities, two were studied in this work for their simplicity, namely, the filtering and the dc-rejection approaches. The former one applies in spatial-frequency domain a filter to decompose the relative shift into slow varying and fast varying parts. The ideal high pass filter is first tested in this work for the estimation of relative offset. Thus, the only processing parameter to be decided is the lower bound of the high pass filter. The dc-rejection method uses the fact that within a limited range, a slow-varying function can be well approximated by using a polynomial of low degree. In this work, polynomial of degree 2 is applied to model the slow-varying components within the range of a moving window. A least square operation is then applied to carry out the relative shift the coefficients of the polynomial. Therefore, the only processing parameter to be decided is the size of the moving window. Though different perspective view points enlighten the development of these two estimation approaches, it should be noted that the underlying mathematical ideas of the two methods are actually the same.

The outstanding issue by now is to decide the processing parameters for the foregoing approaches. Instead of using a fixed value, a try-and-error procedure is developed to meet its operational requirement. A useful reference is that the probability that the deviation of RSI pointing exceeds 0.7 pixel is less than 0.3%. Accordingly, we iterate the processing parameter such that more than 99.7% scan lines will be compensated using offset less than 0.7 pixel. In the mean time, the residual of the relative shift is constantly monitored, a value exceeding 0.35 pixel triggers an alarm of possible exception.

4. Case study

To validate our algorithm and also to examine its robustness, we have analyzed dozens of FORMOSAT-2 scenes. This section uses figure 1 to explain the analysis methodology as well as the results we obtained. First, the relative shift between adjacent scan lines is measured from the raw image. As figure 3(a) shows this relative shift rarely exceed 0.5 pixels. To analyze the characteristics of trembling artifact, we transfer the relative shifts from spatial domain to frequency domain by means of Fourier transform. As figure 3(b) shows this spectrum is characterized by numerous prominent yet exotic spikes sitting in a range between 100 and 400 Hz. Recalling that the relative shifts consist of components from relative offset measurement uncertainty, and the collective tendency of surface features. For the latter two, the signal strengths tend to go weaken as the frequency goes up. It is obvious that trembling artifact contribute spikes to this spectrum.

Figure 3(c) demonstrates the need of relative offset estimation procedure. If one takes relative shifts directly in trembling removal operation, this figure depicts the compensation amount to be used in image restoration phase. As a result, a vertical straight line will be severely twisted. And for this test case, it will be twisted up to 1600 pixels. Figure 3(d) demonstrates the effectiveness of relative offset estimation procedure. In this figure the compensation amount is plotted in red which is actually integrated from estimated relative offset. Obviously the twisting feature is relieved. The green one is the residual relative offset which is deduced by taking out relative shift from the measured relative shift. If one integrates these residual quantities, a result very close to figure 3(c) will be obtained

By applying image resampling operation, a trembling-free image full scene is constructed. Figure 4 shows a patch of this restored image. Compare to figure 2, it is clear the annoying trembling artifact is no longer evident. Above procedures have been repeated for each of our test cases. These cases are randomly picked from FORMOSAT-2 PAN archive and are dated between June, 2004 and May, 2005. The coverage of these images ranged from nature terrain surface to man-made features. Though we do expect for some exceptions, none of our test cases fails. Analysis results obtained from these cases are actually quite uniform and consistent. Base on these analysis results, a fully automatic implementation of the proposed algorithm has been developed and installed in our operational environment.

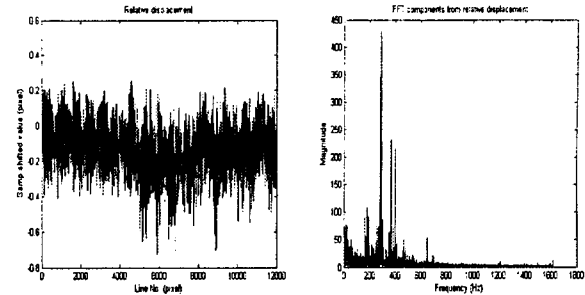


Figure 3(a) Relative shifts

3(b) Frequency components

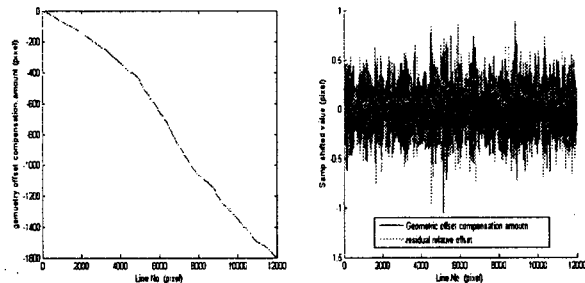


Figure 3(c) Compensation

3(d) Compensation amount and residual relative offset



Figure 4

5. Conclusion

In this work, we describe and analyze the nature of trembling artifact observed on some FORMOSAT-2 PAN products. A 3-stage algorithm is proposed to remove the artifact, which include relative shift measurement, relative offset estimation and a modified cubic convolution resampling operation. Evident by the cases we studied, the algorithm is useful and robust. An operational implementation is also developed to ensure image products a consistent quality.

6. Reference

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