Spatial Resolution Improvement Using Over Sampling and High Agile Maneuver in Remote Sensing Satellite

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Abstract

Spatial resolution is an important parameter in the field of remote sensing. Therefore most of the commercial satellites are designed to obtain high resolution images. But satellite image resolution is limited by satellite design and imaging conditions. In this paper spatial resolution improvement method using over sampling and high agile maneuver is proposed. Satellite collects informations on the target in the satellite flight path along direction and cross direction. Target information is extracted from the collected informations, which are degraded by satellite modulation transfer function. By numerical simulation, we show that over sampling and high agile maneuver can be used to obtain high resolution images at sub pixel level.

Key Word : Spatial Resolution, Over Sampling, Agile Maneuver, MTF

Introduction

Civil space-borne remote sensing started in 1972 with an 80 m ground sample distance provided by Landsat-1. Now, most of the commercial satellites are designed to obtain high resolution images using high technologies [1]. This trends are continued. IKONOS which was launched in 1999 provides 0.82m ground sample distance at nadir in the panchromatic band and 3.24m ground sample distance in the multi spectral bands. Geoeye-1, which will be launched, will provide 0.41m ground sample distance in the panchromatic band and 1.65m ground sample distance in the multi spectral bands. The sub meter level images will be used for applications and services focused on meeting the demanding requirements of land management and national security. Because the applications and the services are very sensitive to spatial resolution, most of current commercial satellites are competing at sub meter level.

Many researches have been studied for obtaining high resolution images. One of them is to make satellite with high technologies. But current technologies have many limitations in optics and electronics. The second approach is to adjust satellite orbit. Small ground sample distance can be obtained by reducing the distance between target and satellite. But the satellite orbit can not be assigned arbitrary due to mission constraints such as life time and revisit time. The third approach is to change remote sensing conditions. Over sampling reduces ground sample distance along track by reducing the sub-satellite velocity or by reducing the integration time of the sensor [2-4]. Push-broom scanners featuring staggered line arrays, which are constructed from two identical CCD lines shifted against each other by half a pixel in line direction can be used for this purpose. But it has a limitation in image performance.

In this paper, a new satellite operation concept and image processing method for obtaining high resolution images are proposed. Satellite collects several images for the same target using over sampling and high agile maneuver. Target information is extracted from the collected information which is degraded by modulation transfer function. By numerical simulation, we show that over sampling and satellite maneuver can be used to obtain high resolution images at sub pixel level.

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Satellite Operation

Most of commercial satellites are designed considering user requirements. Various operation concepts are generated to satisfy the user requirements. According to the operation concepts mission planning and scheduling is implemented [5].

Most of satellites using push-broom scanner collect images by satellite position change in space. This operation is used when satellite takes a long time to change attitude or when a long strip image in the flight path along direction is required. Figure 1 shows strip imaging. Camera line of sight is fixed relative to LVLH during imaging. More advanced operation concept is to take images which are distributed within a large area. Generally images to be collected are distributed in a large area. In order to collect the images, satellite agility can be used effectively. Figure 2 shows multi point imaging. Satellite collects several images which are left or right side from the satellite flight pass. Another mission is to collect a large area image. Most of satellite has a limited swath width due to hardware constraints. Satellite agility can be used to take the ground image whose swath width is larger than the sensor swath width. Figure 3 shows wide area imaging in the flight path along direction. By three collections, satellite enlarges swath width. In this operation, spatial resolution at the first collection and at the third collection degrades comparing with the second collection. Figure 4 shows wide area imaging in the flight path cross direction.

Over Sampling

Most of remote sensing satellites collect images by moving camera line of sight on ground. Camera ground sample distance (GSD) at nadir is determined by camera pixel size, effective focal length and satellite height.

$$GSD_o = \frac{p}{EFL} \times H \quad (1)$$

where H is a satellite height from ground, p is camera pixel size, and EFL is effective focal length.

Satellite GSD degrades from the camera GSD by tilting angle. Satellite GSD in the satellite flight path along direction and cross direction can be represented approximately

$$GSD_A = GSD_o / \cos^2(\theta) \quad (2)$$

$$GSD_C = GSD_o / \cos(\theta) \quad (3)$$

where θ is satellite rotate angle about pitch axis from nadir.

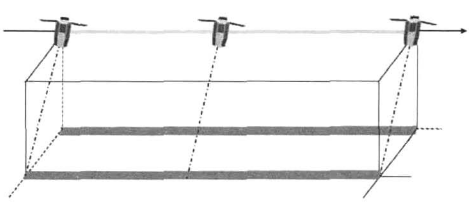

Fig. 1. Strip Imaging

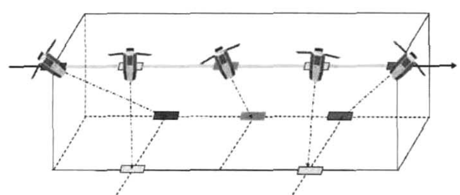

Fig. 2. Multi Point Imaging

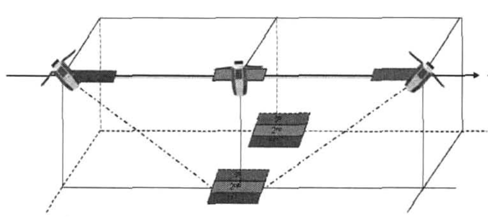

Fig. 3. Wide Area Imaging - Along

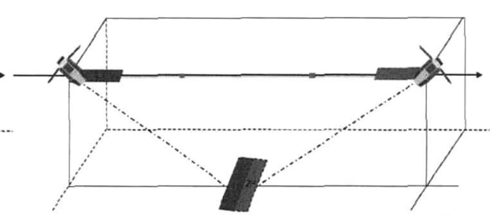

Fig. 4. Wide Area Imaging - Cross

Generally, high resolution satellite has camera electronic unit which reads radiometric value of camera pixel. Sampling rate is controlled to minimize modulation transfer function (MTF) degradation [6]. The sampling rate is synchronized so that ground movement of camera line of sight is equal to satellite GSD in the satellite flight path along direction.

$$GSD_A = V \times \gamma \tag{4}$$

where V is ground velocity of camera line of sight and γ is sampling rate.

Figure 5 shows effects of sampling rate. Most of remote sensing satellites operate in synchronization condition like (a). Ground information is read continuously. When sampling rate is slow, some information can be lost like (b). When sampling rate is fast over sampling occurs like (c). Information number in (c) is more than (a).

Let us assume that satellite collects ground images by camera. Theoretically, satellite camera pixel reads ground radiance value whose size is satellite ground sample distance. In real situation satellite camera pixel reads ground radiance value whose size is larger than satellite ground sample distance due to satellite performance limitation. The degradation in the spatial resolution, which is called by modulation transfer function, can be represented by point spread function. Satellite image at J th camera pixel when time step is K can be represented [7].

$$B[K,J] = \sum_{x=1}^{N_X} \sum_{y=1}^{N_Y} M(x,y) \times S[\alpha \times (K-1) + x, (J-1) \times \alpha_Y + y] \tag{5}$$

where $M(x,y)$ is point spread function, $S[X,Y]$ is ground radiance value at X th and Y th position. Size of $S[X,Y]$ is GSD_A/α_X in the flight path along direction and GSD_C/α_Y in the flight path cross direction. α_X is ground pixel number within GSD_A and α_Y is ground pixel number within GSD_C. α is ground pixel number corresponding to camera line of sight movement during one sampling interval. N_X is ground pixel number in the flight path along direction which is effected by point spread function and N_Y is ground pixel number in the flight path cross direction.

Here $B[K,J]$ is known and $S[X,Y]$ is unknown. Final goal of remote sensing is to find exact solution $S[X,Y]$ using collected information. The collected information can be represented as a algebraic form.

$$B = CS \tag{6}$$

where $B \in R^{K \times J}$ and $S \in R^{(\alpha \times (K-1) + N_X) \times ((J-1) \times \alpha_Y + N_Y)}$.

Eq. (6) has a unique solution if α and α_Y is equal to one, N_X is equal to α, and N_Y is equal to α_Y. But N_X and N_Y is not one because modulation transfer function is not one in real situation. Therefore unique solution can not be obtained from Eq. (6).

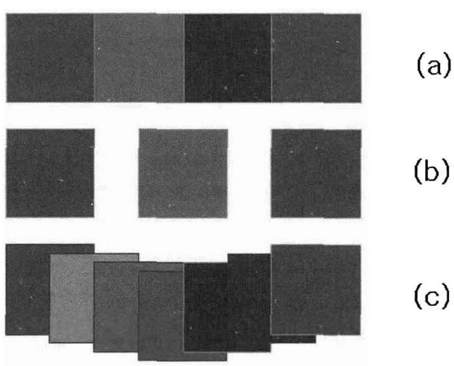

Fig. 5. Effects of Sampling Rate

Now let us consider ideal case when N_X is equal to α_X and N_Y is equal to α_Y. In this case C is $R^{K\times J,\ (\alpha K+(\alpha_X-\alpha))\times(\alpha_Y J)}$. When α_Y and α are equal to one, shape of C becomes similar to square matrix when K and J is large. Though C is not square matrix due to α_X is larger than α in over sampling case, pseudo inverse can be used to find solution S in Eq. (6). Note that size of $S[X, Y]$ in the flight path along direction can be reduced by α_X. It means that over sampling can be used to find high resolution images in the over sampling direction.

$$K_{SYNC} = L_X / GSD_A \tag{7}$$

$$K_{OVER} = \alpha_X/\alpha \times (L_X/GSD_A - 1) + 1 = \beta \times (K_{SYNC} - 1) + 1 \tag{8}$$

where L_X is ground length in the camera line of sight movement direction and β is over sampling number.

Image Generation using Multi Look

In general, many information on the target increases possibility of obtaining high resolution images. Satellite maneuver can be used to increase the possibility. Agile satellite can perform various missions. By modification of wide area imaging in Figure 3, satellite can collect target area image three times more than strip imaging in Figure 1. In this operation, the first collection is performed before satellite arrives at the target area. The second collection is performed over the target area. The third collection is performed after satellite passes the target area. Satellite ground sample distance at the first collection and at the third collection degrades comparing with the second collection. But the difference can be used to extract high resolution images.

In order to maximize satellite image resolution, camera line of sight movement direction can be adjusted. Extreme case is to change camera line of sight path from vertical to horizontal or horizontal to vertical. In this case, multi look number for the target can be reduced from three to two due to satellite maneuver limitation. Though cross at the right angle may not be optimal, the cross at the right angle provides another chance in the point of satellite image resolution.

As described in previous section, over sampling provides high resolution image only in the over sampling direction. But the ground sample distance in the along direction and in the cross direction are simultaneously important for applications such as target detection and identification. Agile satellite maneuver can be used to overcome the drawback of over sampling operation which provides high resolution images only in the over sampling direction. By high agile maneuver satellite collects ground images in the satellite flight path along direction and cross direction like Figure 6. Camera line of sight path on ground in the first collection crosses camera line of sight path in the second collection.

As described in over sampling section, collected information on the first scene can be represented like Eq. (6).

$$\overline{B_A} = \overline{C_A}\,\overline{S_A} \tag{9}$$

where $\overline{B_A} \in R^{K\times J}$ and $\overline{S_A} \in R^{(\alpha\times(K-1)+N_X)\times((J-1)\times\alpha_Y+N_Y)}$

After agile maneuver, satellite collects information on the target area using over sampling. The collected information for the second scene can be represented like Eq. (9).

$$\overline{B_C} = \overline{C_C}\,\overline{S_C} \tag{10}$$

where $\overline{B_C} \in R^{K\times J}$ and $\overline{S_C} \in R^{(\alpha\times(K-1)+N_X)\times((J-1)\times\alpha_Y+N_Y)}$

The information which is obtained in the first collection and the second collection includes information on the same target. For the same target S, following equations can be extracted from Eqs. (9) and (10).

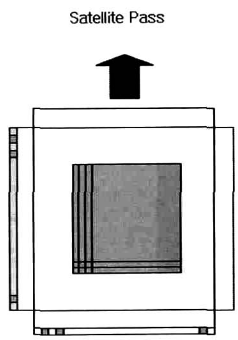

Fig. 6. Multi Look

$$B_A = C_A S \tag{11}$$

$$B_C = C_C S \tag{12}$$

Eqs. (11) and (12) can be combined.

$$B = CS \tag{13}$$

where $B = [B_A^T \ B_C^T]^T$ and $C = [C_A^T \ C_C^T]^T$
Solution in Eq. (13) can be represented by

$$S = C^+ B + N^T E \tag{14}$$

where C^+ is pseudo inverse which satisfies $CC^+ = I$, N is null space of C which satisfies $CN^T = 0$, and E is a free parameter.

As mentioned previously, over sampling does not provide exact solution due to insufficient information. There are many solutions to satisfy Eq. (13). High frequency noise can appear by null space term in Eq. (14). Indirectly it means that the free parameter E can be used in order to improve satellite image performance. For example, the free parameter can be used to reduce the noise when uniform area is shown with pattern noise.

Physically, over sampling operation provides β times more information than synchronization operation. Satellite maneuver provide another β times more information. Finally, over sampling operation and satellite maneuver provides 2β times more information than synchronization operation. It indirectly means that ground resolution can be improved $\sqrt{2\beta}$ times.

Simulation

Car in the parking area is selected for simulation like Figure 7. Ground sample distance of origin image is 10 cm. We assume that satellite ground sample distance is 40 cm. Theoretically one pixel in camera corresponds to 16 pixels in the origin image. In real situation, one pixel in camera corresponds to more pixels due to optical performance degradation and satellite motion. For considering this condition, point spread function like Figure 8 is used. Satellite images are obtained by convolution of the ground images and the point spread function. Satellite image in synchronization is shown in Figure 9. Most of high frequency information disappears. It is not easy to detect the target characteristics such as size and shape. Figure 10 shows over sampling image in the along direction and Figure 11 shows over sampling image in the cross direction. Over sampling number is four in both collections. Though each image provides high frequency information comparing with Figure 9, it is not easy to detect the target characteristics. Figure 12 shows final image which is obtained using proposed method in this paper. Optimization using the free parameter is not performed.

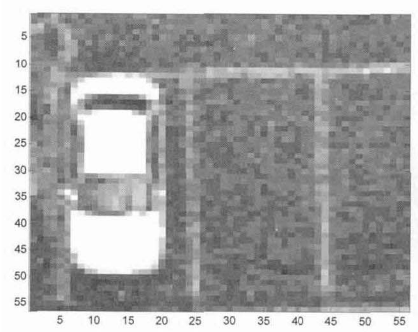

Fig. 7. Origin Image

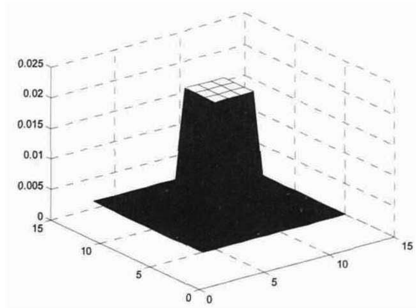

Fig. 8. Point Spread Function

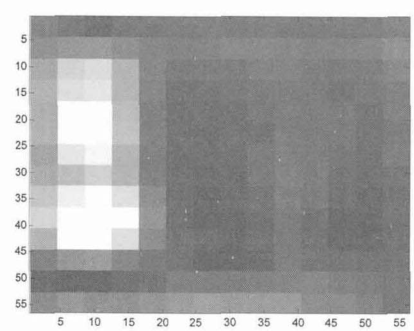

Fig. 9. Synchronization Image

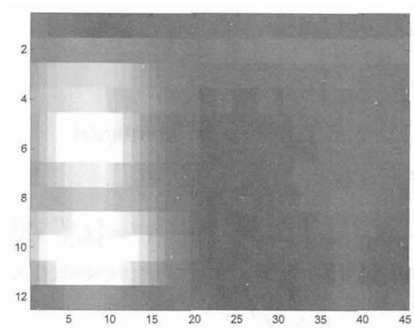

Fig. 10. Over Sampling Image (Cross Direction)

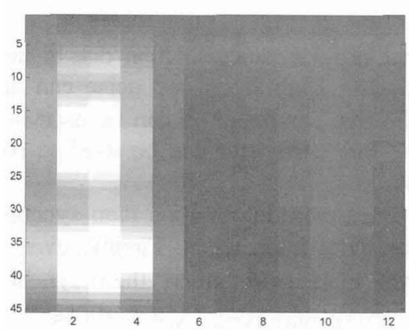

Fig. 11. Over Sampling Image (Along Direction)

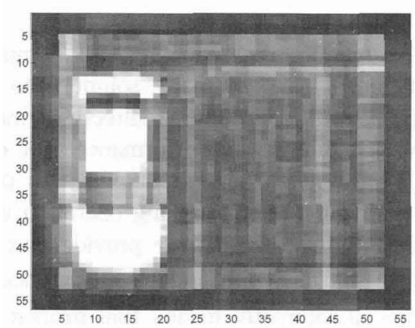

Fig. 12. Over Sampling Image (Final)

Though high frequency noise appears in the image, target characteristics such as size and shape are more obvious. Simulation result shows that over sampling and satellite maneuver can be helpful to obtain high resolution information at sub pixel level.

Conclusions

In this paper, new satellite operation concept and image processing method for acquiring high resolution images are suggested. By numerical simulation we show that high resolution images at sub pixel level can be obtained using over sampling images in the satellite flight path along direction and cross direction. Real satellite operation conditions can be different from simulation conditions. The method presented in this paper will be refined and improved by including real imaging conditions in the future.

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