A Study on Push-Broom Imaging with Image Line Rotation - Data Simulation and Analysis

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Abstract

Obtaining high-resolution imagery requires technological advances in many areas like, payload development, high data rate transmission, spacecraft agility etc. Various techniques are available in literature, to improve the achievable resolution of a given imaging system (Latry and Rouge, 1998). One way to improve the Ground Sampling Distance (GSD) along track can be by reducing the sub-satellite velocity or by reducing the integration time of the sensor. Similarly the across track resolution can be improved by reducing the satellite altitude or increasing the focal length of the camera. All the above techniques have many constraints and need considerable amount of technological advances in high-speed electronics, development of huge optics, precise orbit maintenance and complex algorithms onboard for satellite control.

This paper presents a technique for improving the ground resolution (along as well as across track) of the push broom imaging, by making use of the over-sampling concepts. Over-sampling is achieved by imaging the ground in push-broom mode with a CCD, by tilting it onboard with an angle with respect to the direction of the imaging. Towards this, a study is conducted to see the achievable GSD by a push broom imaging with image line rotation. Necessary images are simulated using the available high-resolution imagery & IKONOS satellite data and results are analysed through qualitative (frequency analysis) and quantitative methods on some representative areas. Results with simulated data sets show an improvement of 1.4 to 1.6 times of the original resolution of the imaging system for an image line rotation of 60°.

Overview

1. Introduction

Obtaining high-resolution image requires technological advances in many areas like, payload development, high data rate transmission, spacecraft agility etc. Various techniques have been explored (Latry and Rouge, 1998), to improve achievable resolution of a given imaging system. One way to improve the Ground Sampling Distance (GSD) along track can be by reducing the sub-satellite velocity or by reducing the integration time of the sensor. Similarly the across track resolution can be improved by reducing the satellite altitude or increasing the focal length of the camera. All the above techniques have many constraints and need considerable amount of technological advances in high-speed electronics, development of huge optics, precise orbit maintenance and complex algorithms onboard for satellite control.

This paper presents a technique to study the achievable GSD by a push-broom imaging with image line rotation. Necessary images were simulated according to the push-broom imaging and analysed through quantitative and qualitative basis on some representative areas. Available high resolution images and IKONOS satellite images are used for simulating the required imagery for this study. Simulated horizontal and vertical patterns representing various frequencies are also used for evaluation.

2. Procedure for Simulation of Images

Two types of images are taken for this study. Firstly realistic images from in-house available high resolution (2.5 m resolution) data (simulated from various sources) are taken as input and the simulated images of 5 m resolution are generated, using the procedures reported in document (Gopala Krishna, B. *et al*, 1999]. In this we combine 2 x 4 pixels (two in across track and four in along track to take care of imaging with along track motion) with a weighted average, to simulate an image taken by a camera with 5 m Instantaneous Geometric Field Of View (IGFOV). This procedure is shown in Figure-1. Similarly for image line rotation case, 2 x 4 pixels in the rotated frame are combined to get the simulated data at half resolution (5 m) of the original. Figure-2 shows the imaging with image line rotation.

The following steps have been used for the simulation of half resolution images for imaging with image line rotation:

(i) Computation of footprint of the required pixels to be combined to generate the half resolution image for the image line rotation of 60°;
(ii) Computing the contribution of each input pixel to be used in generation of an output pixel i.e. weight calculation on input pixel to generate the gray level

of the simulated output pixel;

(iii) Generation of the output pixel with the weighted average of all input pixels, using the weights calculated in the previous step; and

(iv) Registration of simulated images with the original resolution image with a simple affine transformation, to make all the images in the same ground sampling distance.

For normal case i.e. simulation of half resolution image (without image line rotation), similar registration is performed to generate image with the same GSD as original image. These images are given in figures 3,4 and 5 respectively for original, image line rotation and without rotation cases. In this study the rotation angle is chosen as 60°.

As a second test case IKONOS image over Delhi region (1 m resolution of 1024 x 1024 area; as a case of urban region) is taken and images of 2 m GSD (assuming as if a 2 m instantaneous geometric field of view sensor is mounted on the satellite) were simulated with and without image line rotation and the results are analysed. Portions of these images are presented in figures 10, 11 and 12 respectively for original, with image line rotation 60° and without rotation cases.

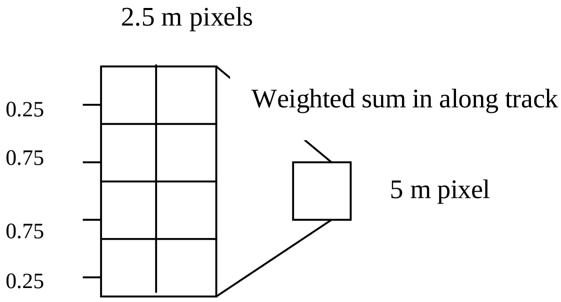

Figure -1: Simulation procedure with weights given in the left hand side

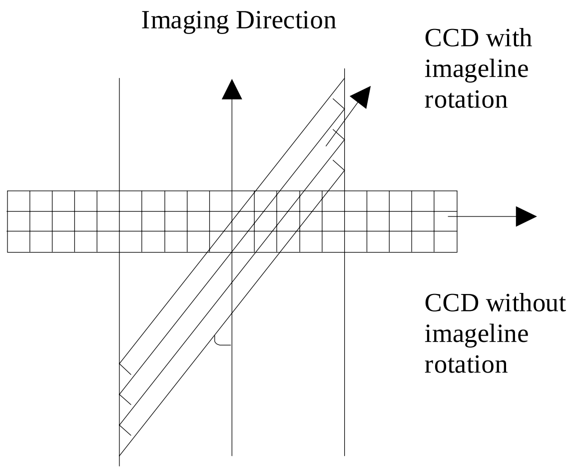

Figure-2: Imaging with image line rotation

3. Results and Analysis

Analysis of the images are done using both qualitative and quantitative measures.

3.1 Qualitative: The results show that the images generated from image line rotation are much better (resolution/sharpness wise) than those images generated in normal way (without image line rotation), but not equivalent to the original resolution image. This can be observed visually from both sets of images simulated from high resolution 2.5 m as well as 1 m IKONOS images. For better comparison at feature level, all images are kept at same scale (GSD) by registering half resolution images with respect to the originals.

3.2 Quantitative: Under quantitative analysis, power spectrum of the images is taken in to consideration for frequency analysis. For case (i) i.e. simulation from high resolution 2.5 m data, some prominent features from the image (like edges, high contrast regions etc,) are identified and an area of 320 x 320 m is extracted and power spectrum is taken. In this, the high frequency power components are dominated by the low frequency components, hence their contribution is not coming out clearly.

In order to bring out the effect of high frequency components on various simulation cases a sub-area of 172.5 x 100 m is selected from all the images of Figures 3, 4 and 5 for analysis (the rectangular feature with high frequency content which is in the middle of Figures 3,4 and 5). Figures 6, 7 and 8 show the power spectrum for these sub areas. From the Figure 6 it can be easily noticed that a frequency component at 0.3 along pixel and 0.1 along scan line is present with a high magnitude. In case of half resolution image generated from no rotation case (Figure-8), the magnitude of this component is almost negligible, where as in the image line rotation case (Figure-7) it is present with a significant magnitude with respect to the original. The relative power content for this frequency component is given in Figure-9, which indicates the relative power for rotated case is 55% of the original. This shows that the rotated case can identify objects of sizes 1.6*a* x 5*a*, which can't be identifiable in non rotated case. This means that one can identify an object of 1.6*a with a 60° rotated 2*a IGFOV system (*a* is the resolution unit of original image) comfortably.

As a second case, a sub-area of 1024 x 1024 m is extracted from IKONOS image over Delhi, which is having good representation of high frequency components. Power spectrum plots for original, half resolution without image line rotation, half resolution with the rotation of image line are taken. Here also frequency components beyond 0.3 cycles/m are seen in the case of rotated image line, where as, these are missing for non-rotation case (figures not given in this paper). Figures 10,11 and 12 show a portion of images from the original, image line rotation and with no rotation cases.

As an additional test case images are also simulated with 2 x 1 m (across x along) GSD for analysis.

The average ratio of power for different frequencies from original to the image line rotation case and no rotation case (2 x 2 m and 2 x 1 m) are plotted and are shown in Figures 13 and 14 along the pixel and along the scan direction respectively. These plots indicate the average frequency response with respect to original (i.e. ratio of average frequencies of original to simulated) for image line rotation/no-rotation cases, basically characterises the MTF of the imaging system. We can observe at 0.35 cycles/m the rotated case gives the ratio around 25 (with respect to original full resolution), where as the 2 x 2 non-rotated image line has a negligible ratio (3 with respect to original). As expected 2 x 1 case gave less magnitude of ratio (15 with respect to original) than the rotated case in pixel direction and 45 (with respect to original) in scan direction, which is more than the rotated case.

In addition to the real images, horizontal and vertical patterns of different frequencies are created and analysed. The results confirm to similar trend as above with the real data sets.

4. Limitations of Current Simulation Exercise

(i) To carry out simulation at a given GSD one requires data samples at least one fourth of GSD. In the present case the data is available at same GSD.

(ii) The rotated image set gives a much larger number of samples. Current simulation exercise uses a simplistic approach for reconstruction. By using suitable reconstruction algorithm like in SPOT-5 (Latry and Rouge, 1998), a better performance improvement can be expected.

5. Summary and Conclusions

- Possibility of improvement in spatial resolution through rotated image line has been studied.
- Simulation has been carried out using 1 m and 2.5 m resolution data sets.
- The results show an improvement (of about 1.4 to 1.6 times IGFOV) in both qualitative and quantitative terms.
- Simulation is limited by the availability of data for demonstration at 1 meter.
- Further analysis is to be carried out in terms of improving the effective resolution of the final images making use of the available system MTF information in the simulation procedure.

6. Acknowledgements

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7. References

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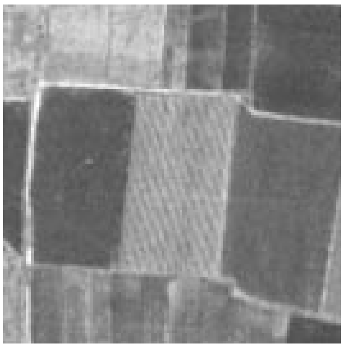

Figure-3: Original 2.5 m (GSD=2.5 m)

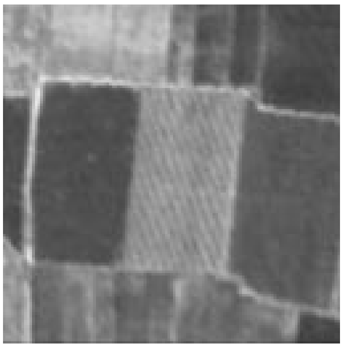

Figure-4: 60° rotated 5 m, registered with respect to original (GSD=2.5 m)

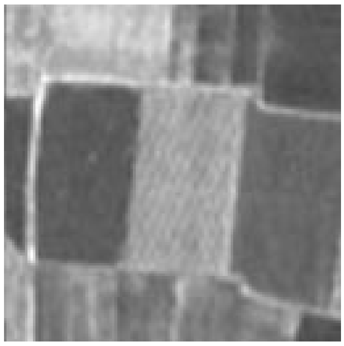

Figure-5: Zoomed 5 m, registered with respect to original (GSD=2.5 m)

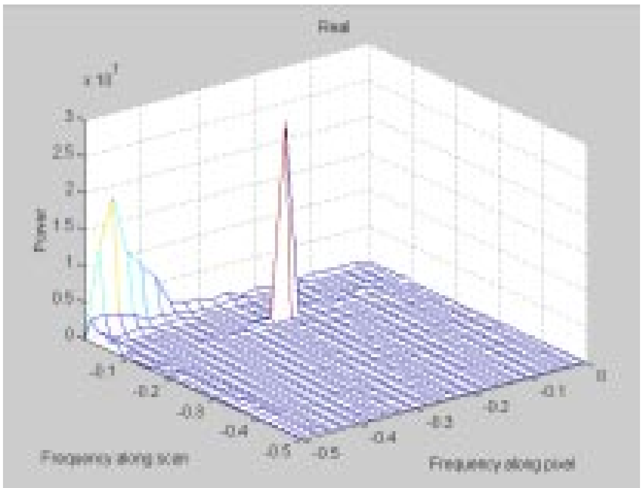

Figure-6: Power Spectrum of Figure-3

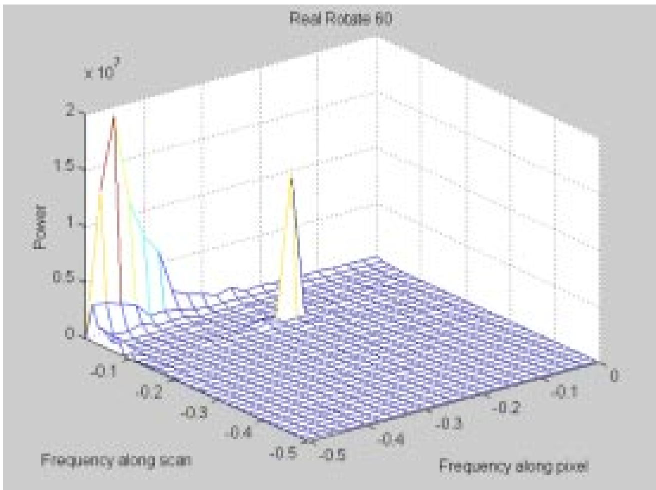

Figure-7: Power spectrum of Figure-4

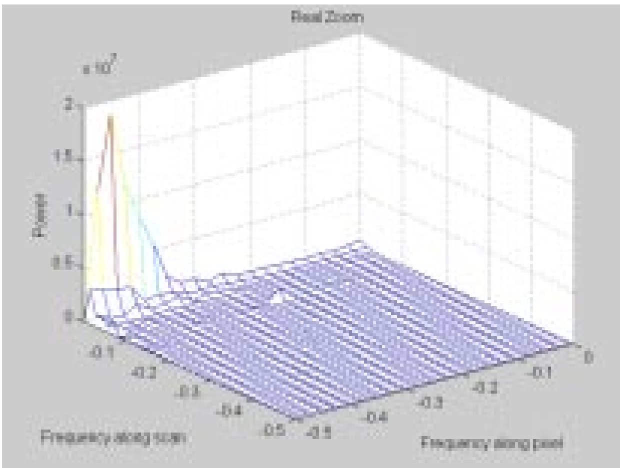

Figure-8: Power spectrum of Figure-5

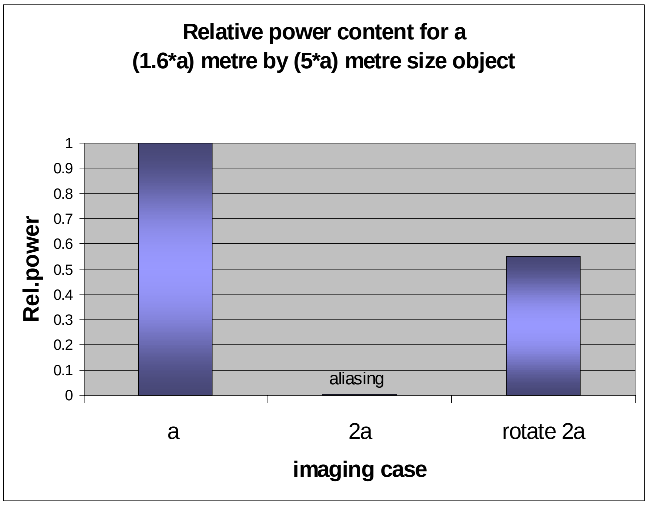

Figure-9: Relative power content of Figures-3, 4 and 5 with respect to Figure-3

Figure-10: A portion of original image used in the study (GSD=1 m)

Figure-11: 60° rotated 2 m image, registered with respect to original (GSD=1 m)

Figure-12: Zoomed 2 m image, registered with respect to original (GSD=1 m)

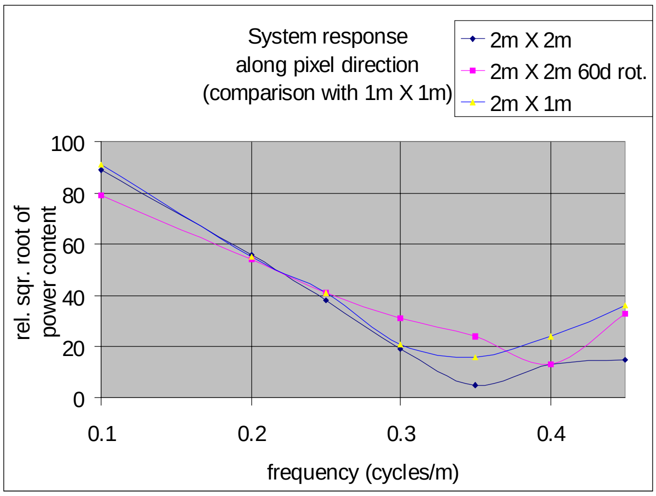

Figure-13: Ratio of average frequency response of rotated and zoomed images with respect to original along pixel direction

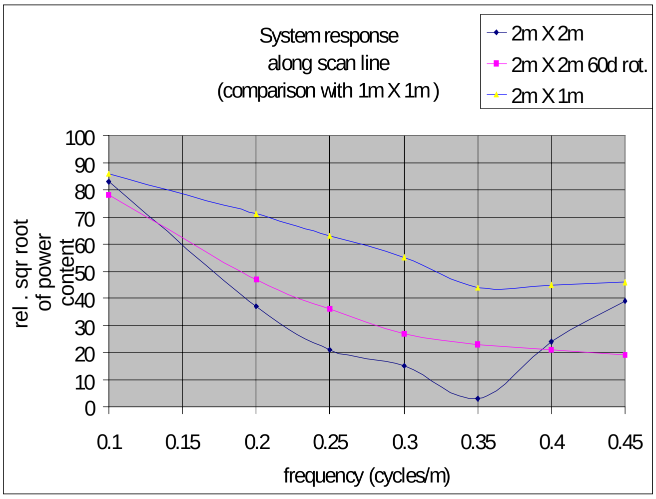

Figure-14: Ratio of average frequency responses of rotated and zoomed images with respect to original, along scan line direction