IMPROVEMENT OF MICRO-SATELLITE MULTISPECTRAL PUSHBROOM SENSOR BAND CO-REGISTRATION: AN XSAT CASE STUDY

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Abstract: Small sized, lightweight micro satellites are increasingly common within the earth observation community. This class of satellite can offer a good balance of payload capacity and low deployment cost. XSAT is a micro satellite designed and built by Nanyang Technological University, Singapore which carries a multispectral optical pushbroom sensor with NIR, red and green channels and a designed GSD of 10m. A known and expected tradeoff with smaller satellites is a lower level of platform stability. If the payload is a pushbroom multispectral camera, this instability would result in band co-registration challenges if a rigid camera model is the only model used to perform band stacking. This problem is compounded if high accuracy, high timing resolution pointing information is not known and recorded at imaging time. Micro satellite attitude instability is primarily a combination of lower frequency attitude control loop effects, and higher frequency jitter due to mechanical vibration. To improve image band stacking, XSAT's image processing software includes two components: 1) a variable order polynomial model to remove the lower frequency drifting, and 2) an inter-band feature matching algorithm to remove the higher frequency jitter. The first component has been described in a separate paper published in ACRS2011 and ISPRS2012. In this paper we describe work done on the second component. This component implements a feature matching algorithm in moving search windows placed at evenly spaced intervals throughout the image. Within these windows, feature edges are extracted using a Sobel edge detection operator and matching features are located in other bands by searching for locations in them with the highest cross correlation coefficient between the Sobel operator outputs for the two bands. Finally, a table of offsets is built, and interpolation is performed to produce a resampled band stacked image with the jitter accounted for. Results for this experimental approach are presented.

INTRODUCTION

XSAT was launched in May 2011 and has been in active service since then. It has performed over 250 imaging missions and captured images covering locations as diverse as the Antarctica, Africa, North America, Continental Europe, Middle East and Asia. Its main duties are to serve as experimental platform for processes and technologies for micro satellites and to participate in environmental monitoring efforts including fire monitoring activities. It is a member of Sentinel Asia. XSAT carries a pushbroom sensor with three bands: NIR, Red and Green. CRISP regularly processes data from XSAT to produce colour composite images based on the three bands.

A challenge encountered when compositing the colour image is band co-registration. If the three bands don't align in a predictable manner, rigid camera models alone will not produce high quality output. The end product will have reduced colour coherency. Certain portions of an image may exhibit colour fringing which would require further operator intervention. This uncertainty is largely due to two factors:

1) Macro instability due to attitude control drift resulting in long baseline deviation from desired sensor ground track.
2) Micro instability due to attitude control system random noise resulting in higher frequency jitter.

The first cause of instability can be ameliorated through the use of ground control points and warping the image using high order polynomials. This is a global solution and its use in XSAT image processing has been detailed in a paper by Kwoh et al. [1].

The second cause of instability is of a higher frequency and will result in difficulties in creating colour images from the three bands. The higher frequency and random nature of jitter makes global high order polynomial solutions unwieldy. Local solutions have been proposed in various literature [2].

In this study, we wish to 1) identify the extent of the jitter and 2) propose a suitable corrective method.

METHOD OF EXAMINATION OF XSAT PLATFORM JITTER

Figure 1 shows the exaggerated effects of jitter on the output of a pushbroom sensor.

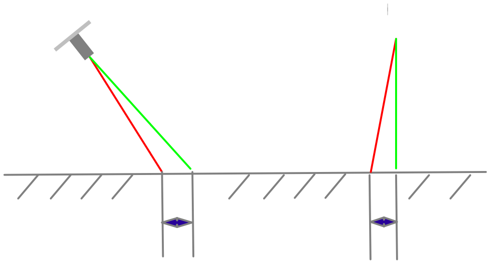


Figure 1: Effect of pitch jitter on pushbroom sensor

Instability in pitch will cause a pushbroom's spatially displaced line sensors to have an offset in the time a ground feature is recorded in the various channels. This offset in time translates into an along track offset in the image when the same ground feature is recorded.

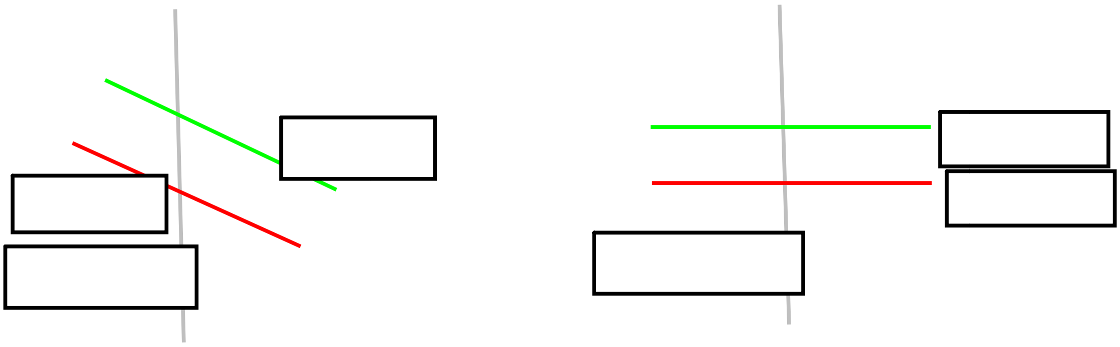
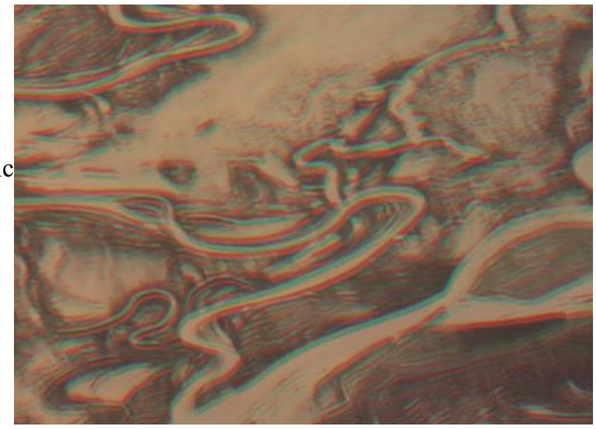


Figure 2: Effect of yaw jitter on pushbroom sensor

In Figure 2 the exaggerated effects of yaw jitter is shown. A common feature on the ground would show up as an across track offset between the channels.

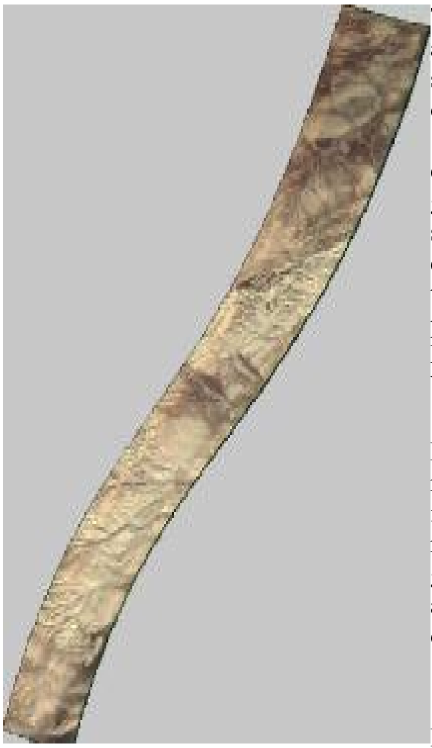
Jitter by nature is a higher frequency phenomenon compared to platform drift. This frequency is high enough that the rate of logging of emphemeris data on XSAT is too low to completely capture it. However, IRIS, XSAT's opto-electronic payload, has a high readout rate and since jitter effects manifest in the local offsets between channel images, the extent and nature of the platform's jitter can be studied by observing where common ground features present in the



various channels. Teshima Y. et al. elucidates the problem and proposes this same approach for attitude estimation for TERRA. [3][4]

Figure 3: Effect of uncorrected jitter on stacked image

In this study, we choose the red channel as the reference channel. On IRIS, the red line sensor is located closest to the optical axis. We also select the green band to compare with the reference.



To perform this study, a long strip is selected from a recent image acquisition mission over Alaska, USA. The georectified browse image is shown in Figure 4. In this image, the drift has been corrected using 3rd order global polynomial correction with the help of ground control points. 1290 square sub-images measuring 200 pixels are extracted from the red channel in a line down the centre of the image starting from the top. The green channel is then examined for the location of each of the reference sub-images. Their across track and along track offsets are recorded in pixel quantity. The centres of the sub-images are 50 pixels apart in the along track direction. This high density of sub-images corresponds to a reference point every 0.075 seconds of flight time, or a frequency of 13.3Hz. Since XSAT's attitude control system operates at a much lower frequency, we can be reasonably certain that the jitter will be fully uncovered by this study.

Because of the large number of reference sub-images, it was not possible to manually search for correspondence in the green channel. An automatic image registration method is used. This technique is based on the normalised cross correlation between the brightness values of the red and green sub-images. The red and green bands are suitable for this form of automatic registration as normalized cross correlation gives good results over a wide variety of ground cover types.

Figure 4: Image used in this study. Alaska, USA, 20120409, XSAT.

RESULTS OF JITTER STUDY

The results of the jitter study is shown below. Figure 5 shows the across track offsets and Figure 6 show the along track offsets. It can be seen that the frequency of the jitter is much higher than the low frequency drift of the platform that was corrected using the 3rd order global polynomial. The magnitude of the maximum offset in the along track and across track directions are measured to be -50 pixels and -10 pixels respectively. This occurs in the early part of the imaging operation. A possible cause of this large initial offset could be that XSAT had not completed the manoeuvre to point IRIS at the imaging target. The maximum excursion after settling down at Time=25 seconds is measured at 9 pixels in the across track direction and -19 pixels in the along track direction. After settling down, XSAT's jitter effects on the image seems confined to a band of between 2 and 9 pixels across track, and -20 and 2 in the along track directions. Future work will include the study of many more image strips to determine if these magnitudes are typical. Furthermore, an attempt may be made to translate the pixel offsets to attitude vectors for a more complete understanding of the phenomenon, especially in preparation for any future software upgrades for XSAT. For this study, the goal of uncovering the pixel offsets is to find a method to compensate for them in post processing.

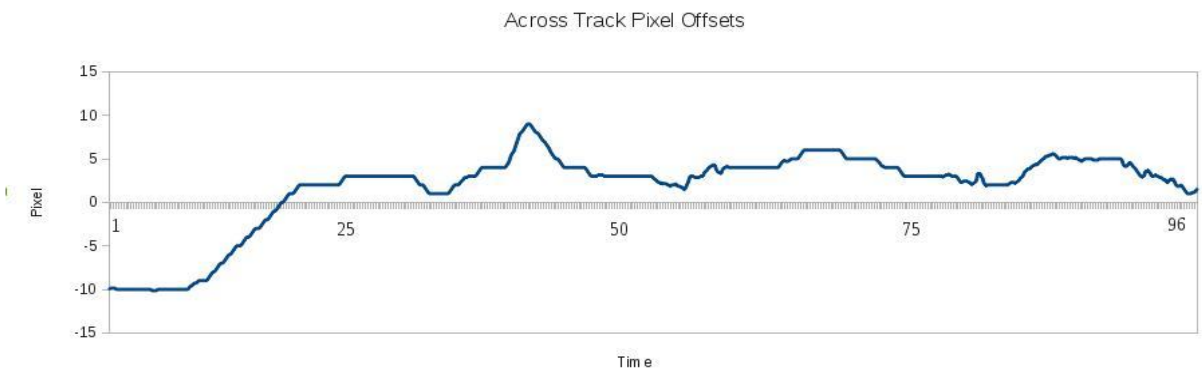


Figure 5: Across Track Pixel Offset

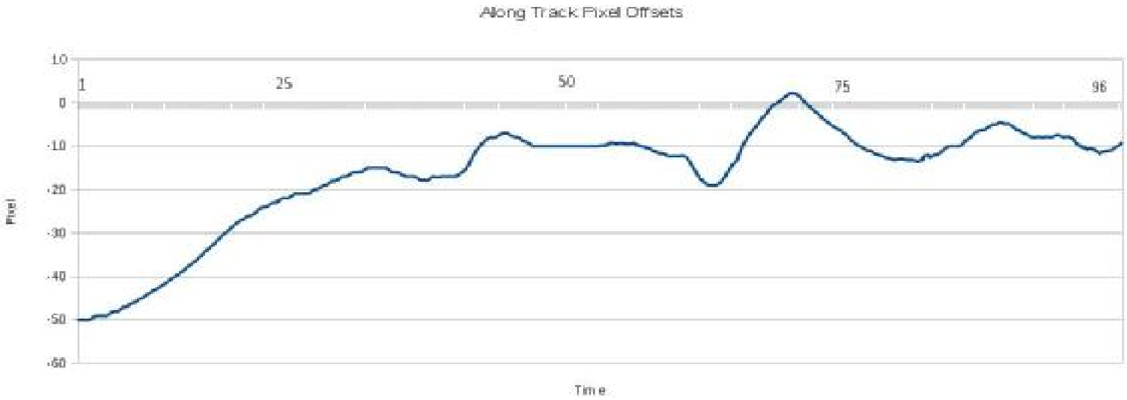


Figure 6: Along Track Pixel Offset

COMPENSATION OF PIXEL OFFSETS DUE TO JITTER

A goal of this work is to produce a method of correcting the offsets. This would allow the production of stacked colour XSAT images at a lower time and manpower cost, especially if the method can be made automatic.

The technique of using normalized cross correlation to register the red and green channels was used to study the jitter effects. This could not be successfully deployed to register the red and NIR bands. However, by applying the technique to the Sobel filtered red and NIR channels, a suitable level of registration reliability can be achieved. Examples of red and NIR channels processed using a Sobel filter are shown in the following diagrams:

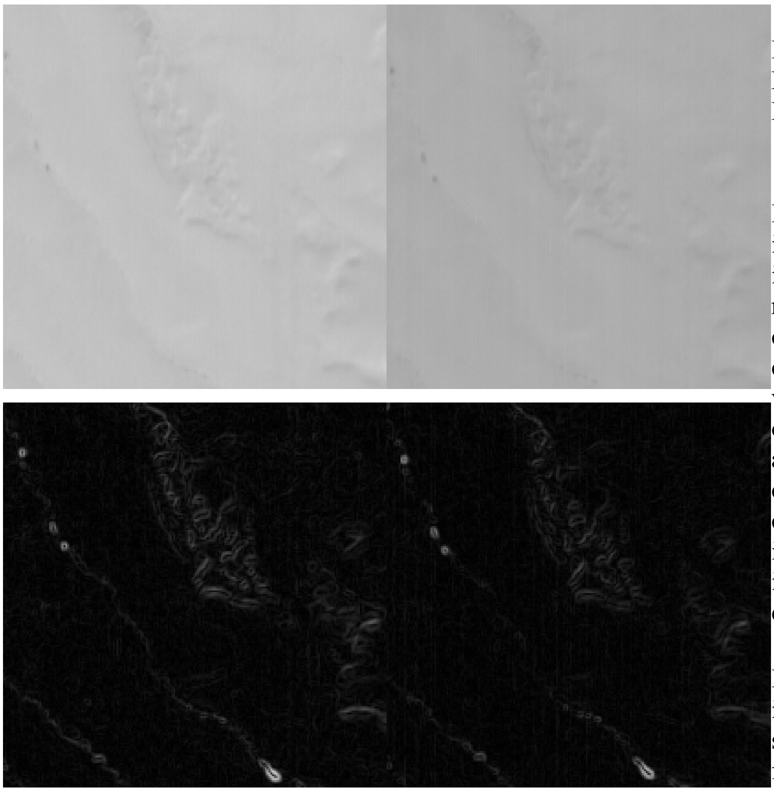


Figure 7: Top Left – Red, Top Right - NIR, Bottom Left – Red Sobel Filtered, Bottom Right - NIR Sobel Filtered

In this example extracted from the Alaska image, it can be seen that the low contrast images will present difficulties for manual registration, and normalized cross correlation will also produce a fit with low confidence. However, the Sobel filtered version present are easier for the human operator and for the cross correlation algorithm to find a match of high confidence.   The ability to produce high confidence registration in low contrast sub-images is crucial to turning the algorithm into an automatic tool that finds matches even under difficult conditions.

In another example (see Figure 8) from an image of an inland reservoir in Brazil surrounded by farmland plots, the Sobel filtered NIR and red channels successfully register with each other automatically. Together with a successful green to red registration, the full colour image is produced. It can be seen that even through the red and NIR channels look distinctly different due to the large differences in brightness and contrast, the overlay of the red and NIR sub-images indicate that the normalized cross correlation algorithm was able to find a suitable registration. The ability to find a match even though the images look different is necessary to the successful deployment of the algorithm in an automatic registration tool as we do not want operator intervention in the selection of sub-images as far as is possible.

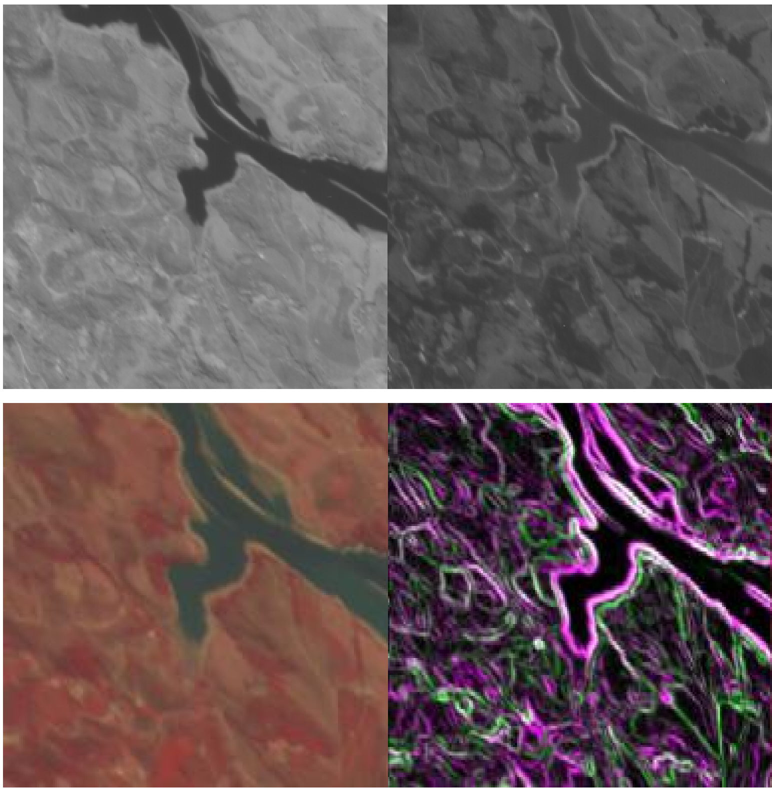


Figure 8: Top Left – NIR, Top Right - Red, Bottom Left – Colour, Bottom Right - NIR Sobel Filtered overlaid with Red Sobel Filtered

A system is then devised to automatically select sub-images in a grid spanning the whole image. The green sub-images are registered to the red image using the normalised cross correlation method, and a copy of the red image and the NIR image are first processed using the Sobel filter, then co-registered using the normalized cross correlation. In this way, a table of tie points registering the green and NIR bands to the red reference band is created. In this table, the across track and along track offsets for NIR and green are recorded for the location of each sub-image in the grid.

In the jitter study, the maximum steady state excursions were observed. The search for matching sub-images is speeded up by constraining the search window to twice the maximum steady state excursions.

The spacing of the grid is of some importance as it has a bearing on the amount of time a human operator needs to spend quality checking the registrations. Also, the chosen spacing should not be too low as to under represent the jitter's highest frequency. From studying the jitter's characteristic, we know that the highest frequency is about 2Hz. This translates to an along track spacing of about 1200pixels. This is chosen as the default along track grid spacing. As for the across track spacing, an arbitrary spacing of 1000 pixels is chosen. Both these spacings are open to refinement in future studies.

Having produced a grid of offsets, the next step is to interpolate between them to produce offsets for each pixel in the NIR and green bands. In this study, we choose to use 3rd order Hermite polynomials. This is a local solution that interpolates the offsets in a smooth manner. To study the quality of the model, we also employ 3rd order Bezier splines for comparison. A thorough explanation of the Hermite polynomial and Bezier spline is beyond the scope of this paper.

To investigate the effectiveness of the two interpolation techniques, we deploy them against the offset data used to study jitter in the first part of the study. The dense, 50 pixel wide spacing is a close analogy to the actual movement of the satellite body and will serve as reference for the interpolation models. Each interpolation technique is used to interpolate tie points at various grid spacings varying between 300 and 6000 pixels along track, and the RMSE is calculated against the reference offset data at the reference dataset's 50 pixel intervals.

The results of the investigation into the various interpolation techniques at various spacings is presented in Tables 1 and 2.

	300	600	1200	3000	6000
Hermite	0.734	0.755	0.750	0.766	1.086
Bezier	0.734	0.748	0.745	0.761	1.154

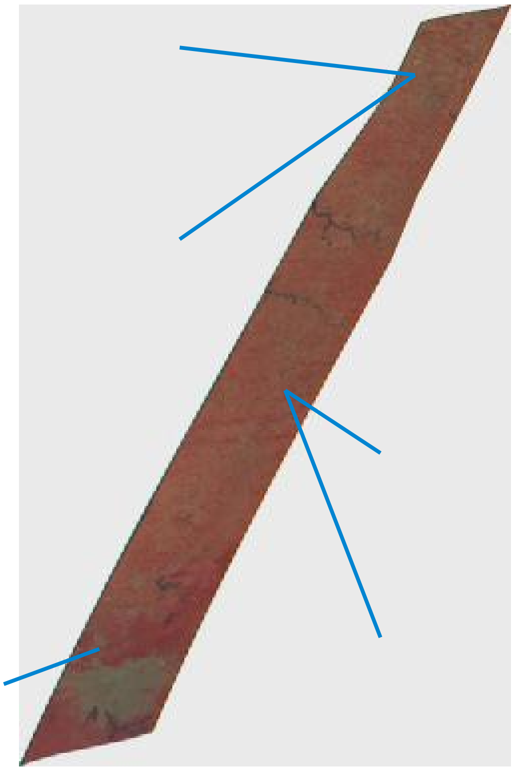
Table 1: Across track RMSE

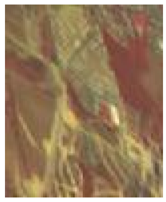
	300	600	1200	3000	6000
Hermite	1.503	1.521	1.443	1.443	2.983
Bezier	1.503	1.514	1.434	1.434	3.876

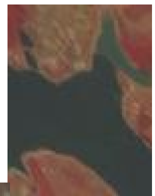
Table 2: Along track RMSE

From the tables, it can be seen that both the techniques perform best at a grid spacing of 1200 pixels. Neither technique seems to offer a clear advantage in modelling accuracy. A choice is made to select the 3rd order Hermite polynomial as the default interpolation technique. The along track RMSE of 1.443 at the chosen grid spacing means that an image at 100% may still have a small amount of observable fringing characteristic of misalignment in certain parts of the image. However, this is weighed against the convenience of the relatively intervention free nature of the algorithm, and the ability to quickly produce fully stacked colour images from the entire imaging strip.

Finally, the stacked image is geo-corrected using a global 3rd order polynomial with the use of ground control points. An example of a fully stacked, geo-corrected image is shown in Figure 11. The image is approximately 50km wide and 480km long.







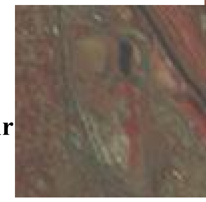


Figure 11: Sao Paolo, Brazil, 201120409

CONCLUSION AND FUTURE WORK

In this study, we analysed the nature and magnitude of the offsets due to jitter. The knowledge gained from that study helped in the design and development of a system used to correct for jitter effects. This system makes use of normalized cross correlation to co-register sub-images from the various bands, spaced 1200 pixel apart in the along track direction. Sobel filtered versions of the red and NIR channels are used in the co-registration process. Local 3rd order Hermite polynomial interpolation is then performed on the image to produce a fully stacked image with a high degree of colour coherency.

Future study will include the conversion of pixel offsets to actual attitude vectors with the addition of TLE interpretation and timing information. Also, a study on the interpolation techniques will be conducted to improve the RMSE of the final result.

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