Strip Mosaicing of Satellite Data Having Step and Stare Imaging

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Abstract

A satellite operating in a step and stare mode, having multiple CCDs (mounted with some along track offset) imaging the ground in such a fashion that there is an overlap between them, exhibits some interesting behavior. Due to the variable attitude rates of the satellite at different points of time, the same feature in the overlap region of the image strips turns out to be of different dimensions and/or orientation. Even after geometric correction of individual strips, this distortion can't be removed completely due to the uncertainty present in the attitude rates. Therefore, like in conventional mosaicing, simple shifting (after geometric correction) of images and trying to join will result in misalignment in features, since the bias between adjacent strips (both in vertical and horizontal direction) is varying as we go down the strip. Hence if we align a feature at the top of the strip, the features at the bottom will be misaligned and vice versa. The shape of the overlap region is also not linear and is in a wavy fashion. This also increases difficulty in mosaicing. This paper addresses the approach developed by Data Products Group, at Space Applications Center for operational generation of mosaics for such data.

Overview

1. Introduction

A satellite containing a set of CCD arrays will individually view segments on ground and transmit those individual segment images. Ground processing is done to join these individual strips of images so that one gets a single image out of this. This combined single image is called a mosaiced image. A large area of image is preferred in comparison to individual strips, as it is easier to locate on a map since it has more identifiable features in it. Therefore, the need for mosaiced images is high, and these images are constantly in demand.

Adjacent images having an overlap can be aligned and stitched seamlessly in such a way that the entire image looks like one single image (Gopala Krishna B. *et al*., 1994). Conventional remote sending satellites operate in a mode in which it is viewing directly on the ground at nadir. This mode is simple since the attitude rates are not varying much, which results in images that don't have much variation in the overlap region.

As shown in the Figure 1 (a) the mosaicing of images of these kinds of images are simple, as we just have to shift one image and stitch the two images using conventional mosaicing procedures (Albert, L. *et al*., 1993).

Till now there have not been many satellites, which use step-and-stare mode of operation. Step-and-stare is used to reduce Ground Sampling Distance (GSD) and therefore increase image resolution. A satellite operating in such a mode, having multiple CCD arrays (mounted with some along track offset) and imaging the ground in such a fashion that there is an overlap between them, exhibits some interesting behavior. We take, for example, a satellite containing four arrays of CCDs, which are arranged in such a fashion that it results in 4 strips of images with an overlap of around 400 to 600 pixels between adjacent strips. In the overlap region, the same feature is imaged some time (approximately 1.2 to 3 s) later (or earlier) by the other strip. Refer Figure 2 for a possible arrangement of the CCDs on the platform of the satellite. Due to the variable attitude rates of the satellite at different points of time, the same feature in the overlap region turns out to be of different dimensions. Even after geometric correction of individual strips, this distortion can not be removed completely due to the uncertainty present in the attitude rates. Therefore like in conventional mosaicing, simple shifting (after geometric correction) of images and trying to mosaic will result in misalignment in features, since the bias between adjacent strips (both in vertical and horizontal direction) is varying as we go down the strip. Hence if we align a feature at the top of the strip, the features at the bottom will be misaligned and vice versa, as shown in Figure 3. The shape of the overlap region is also not linear and can be in a wavy fashion (Singh, A. K. *et al*., 2002). This also increases difficulty in mosaicing. This paper describes how such strips of images imaged by a satellite in step-and-stare mode can be mosaiced.

The approach adopted here works for an operational system but can be easily modified for offline processing as well. It requires an image-to-ground and ground-to-image model using which one can determine common features in the overlap region. This is used to eliminate user interaction, which would have required, otherwise, the user to identify common features in the overlap region interactively.

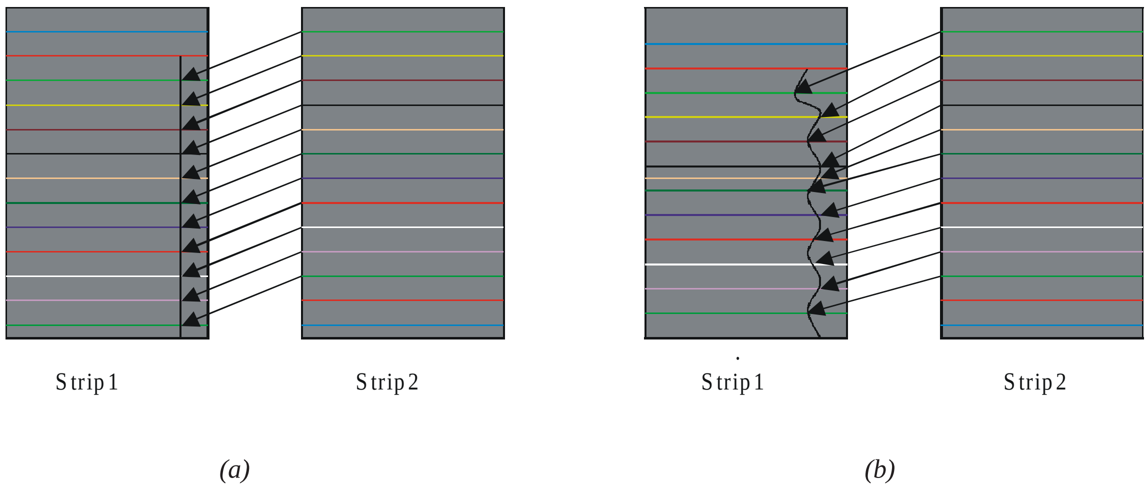

Figure 1.

(a) ***Conventional images (non step-and-stare) have a constant bias in the scan and pixel direction.***

(b) ***In a step-and-stare satellite, the bias is varying in both, scan and pixel directions. (Figure shows exaggerated view)***

The developed algorithm automatically detects common features in the overlap region, using attitude information along with image correlation, and modifies the geometric correction grid file in such a way that the final images of adjacent strips, after geometric correction and resampling, have a constant bias, as in a conventional (constantly nadir looking) satellite images. Therefore using conventional mosaicing procedures these geometric corrected strips of images can be stitched together to form a mosaiced image.

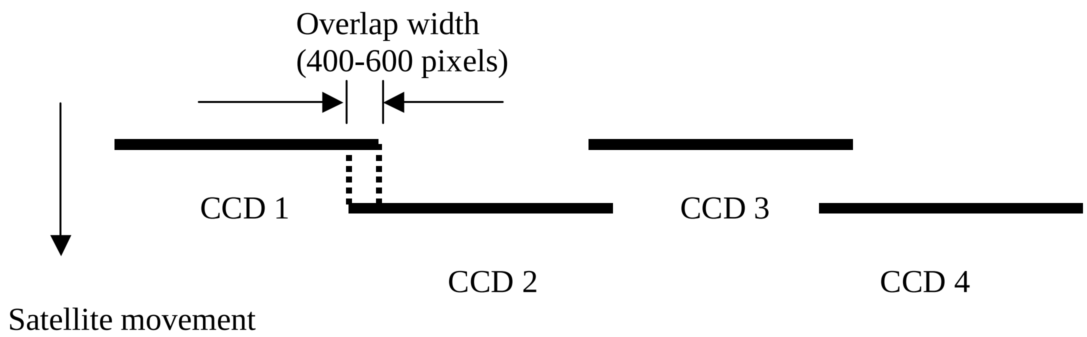

Figure 2. CCD arrangement in the satellite.

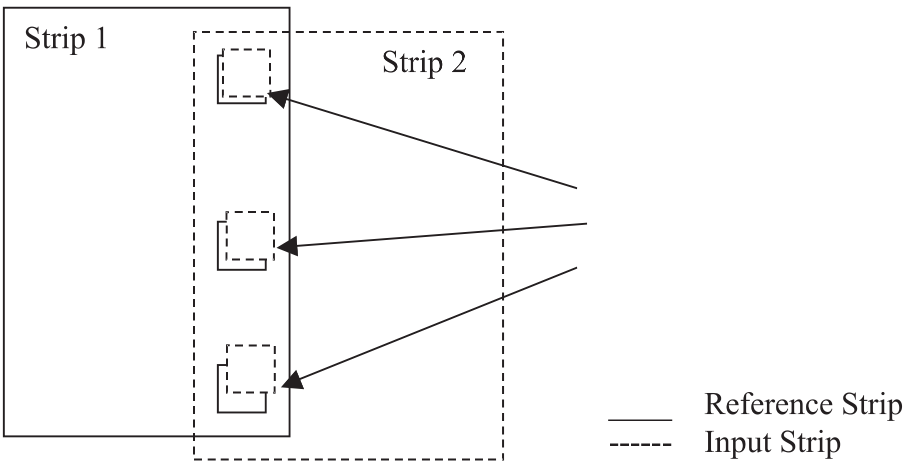

Figure 3. Showing feature misalignments in the overlap region

2. Methodology

In conventional mosaicing the entire process could be divided in the following steps.

(a) **Strip-to-strip registration:** This involves normal geometric processing of images with respect to ground. In a normal chain of operations, while processing data products, a geometric correction grid is generated which provides a mapping between the output and the input. This mapping is stored in a file, which is termed as the grid file. This mapping indicates, for every pixel in the output image (Geo Image) where does the same pixel lie in the input image (Rad Image). Following is the sequence of events during normal processing.

- Data download from media.
- Radiometric correction
- Grid Generation
- Resampling

(b) **Joining of images**: These images are then shifted so that their features in the overlap region coincide. These are stitched together so that a combined single image is formed.

In the case of a satellite having step-and-stare mode of imaging, the features in the overlap region are not alike. The differences in the features in the two strips, after the conventional geometric correction, are as shown in Figure 3. The misalignment varies throughout the strip. Moreover the shapes and orientation also minutely change (not shown in the figure). The approach adopted for mosaicing of data from such a satellite involves updating the geometric correction grid files with respect to this feature misalignment in the overlap region, taking geometric correction grid of one of the strips as reference. The magnitude of feature misalignment is calculated from the radiometrically corrected images using automated methods.

The current approach is to compute the estimation errors and then correct them so that the final images are simple to mosaic. The methodology consists of the following steps –

2.1 Estimation of misalignment: A point is taken in one RAD image (radiometrically corrected) in one strip (in the overlap region) and the same feature is located in the other strip using image correlation. We then estimate the same feature using image-to-ground and ground-to-image models. We call this point as *estimated value* and the method is called *estimation*. The uncertainty in rates will introduce errors during estimation and will result in incorrect identification of the point in the other strip. The difference in the actual value (found by correlation) and the estimated value is termed as *estimation error*. The error in the scan direction is called Δs (delta scan) and in pixel direction is called Δp (delta pix). This is shown in Figure 4 and Table 1. These errors have to be removed in order to have resulting images in such a way that they have a constant bias throughout the image, as we go along track.

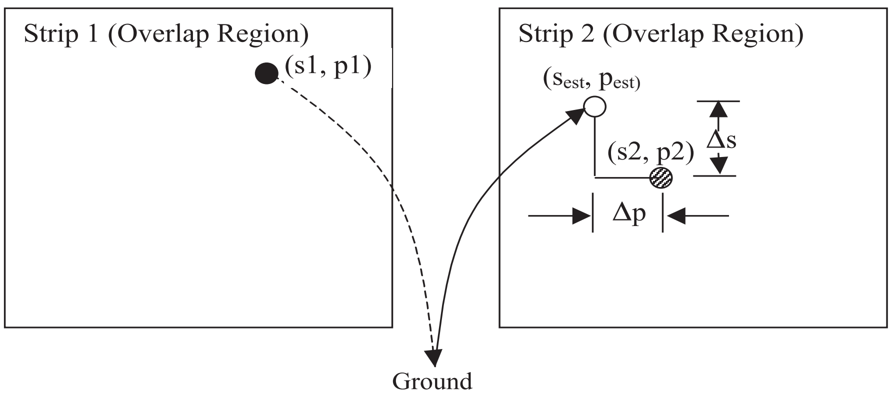

Figure 4. Showing computation of estimation errors.

Table 1

------	Image to Ground (I2G)
_____	Ground to Image (G2I)
●	Feature in the image
● (grey)	Point found using image correlation corresponding to feature ●
○	Estimated value using I2G and G2I point at this position.
(s1, p1)	Scan and Pix of feature in reference strip
(s2, p2)	Scan and Pix of feature in input strip
(s_{est}, p_{est})	Scan and Pix using estimation.
Δs	Estimation error in scan(along track) direction. ($\Delta s = s2 - s_{est}$)
Δp	Estimation error in pixel(across track) direction. ($\Delta p = p2 - p_{est}$)

2.2 Characterization of misalignment: Figure 5 shows a plot of Δs and Δp with respect to time (or scan line in the reference strip). Different cases have different behavior. However, analysis shows that a fifth order polynomial fit is sufficient in this case. It is also noted by the results that fifth order is working well and we do not need to go for a higher order.

2.3 Incorporation in geometric correction: It is practically not feasible to find out estimation errors at each scan line, as it would take a lot of time because image correlation is a compute intensive job. Therefore estimation errors are found out at equal intervals of scan-lines, and a polynomial model is fitted on them in along and across track directions. We compute estimation errors using geometric model and image correlation at every 10^{th} scan line. Finally a fifth order polynomial is fitted between these errors and time (scan line) so that we can interpolate and find out the estimation errors even where image correlation fails or not able to locate points due to homogeneous regions. The grid files are updated using these estimation errors. The scan and pixel values in the grid file are updated by subtracting these estimation errors from them. This stage of grid file updation is called *PreMosaic.*

A major hurdle during *PreMosaic* is that in the presence of homogeneous regions (water, snow, cloud, desert), image correlation is unable to determine common features in the overlap region. Therefore there will be cases where one might not get RCPs (relative control points) for some parts of the scene. Polynomial fitting also helps in these cases and therefore this becomes a robust system, which can mosaic even homogeneous cases with few RCPs. Interpolated values were used to compute estimation error where RCPs were not found. Image correlation was strengthened by doing reverse correlation by swapping the input and search windows. This increases reliability of the match points found and in turn helps in correct determination of estimation errors.

These updated grid files are used during *Resampling* to generate geometrically corrected images of all the four strips. In the resultant geometrically corrected image files the overlap region is linear in nature and the common features in the overlap region, between two adjacent strips, have the same shape, size and orientation. Therefore a constant bias is achieved between the geometrically corrected image files (geo files) after grid files are updated.

These geo files are simply joined together (using conventional mosaicing procedures) resulting in a single image with a seamless joint at the overlap region, which is called *stitching of images*. In this case since the images were viewed on the same day without much time difference between them, the radiometric differences were not much, therefore there is no need of radiometric adjustment. However, algorithms have been developed to take care of radiometric normalization, if required. In future radiometry could change due to CCD degradation over time.

Following is the sequence of events for Mosaic processing.

1) Data download from media.
2) Radiometric correction
3) Grid Generation
4) PreMosaic
5) Resampling
6) Mosaic

Notice Premosaic after Grid Generation and Mosaic after Resampling.

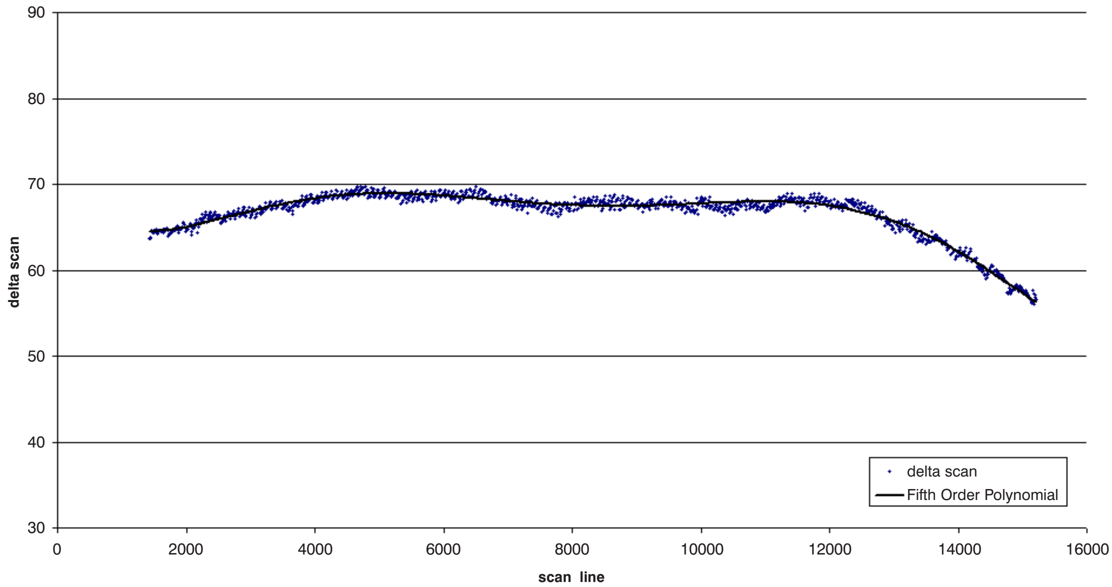

Figure 5(a). Estimation Error (Delta Scan)

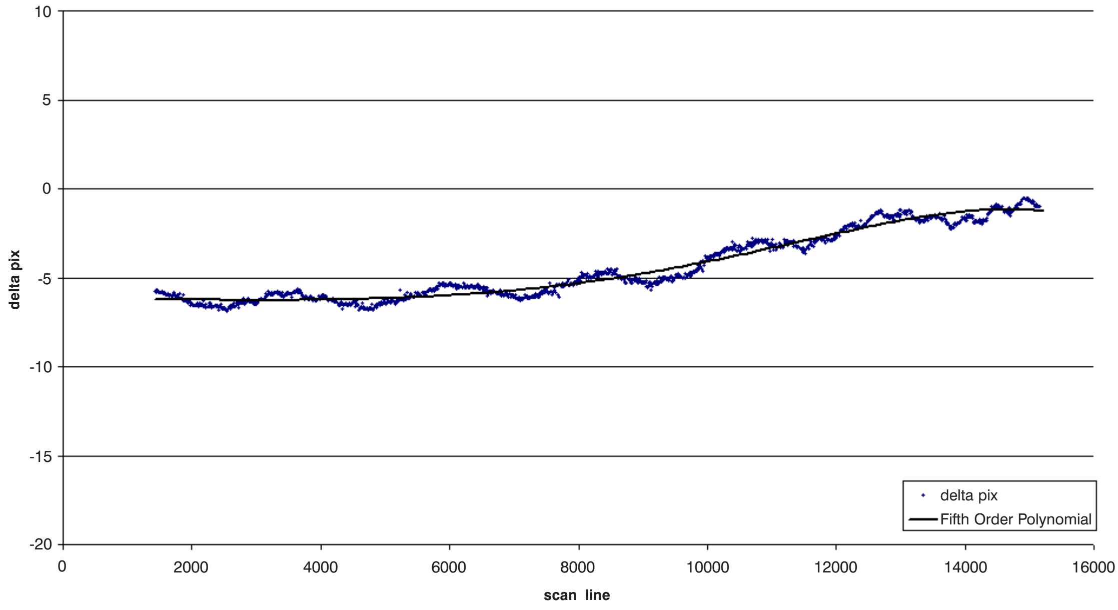

Figure 5(b). Estimation Error (Delta Pix)

3. Results

Figure 6 shows three samples that were mosaiced using the above mentioned approach. The samples show three different cases (homogeneous, linear and circular features). The strips are of high geometric resolution and their length is of 16384 lines and it represents 16 km on the ground. These images show varying magnitudes of misalignment as we go down the strip. Figure 6(a) is at the top of the scene and is a slightly homogeneous region. Figure 6(b) is at middle of the scene and contains a linear feature. Figure 6(c) is at the bottom of scene and shows a circular feature. The results show that the images were perfectly mosaiced.

4. Conclusions

The presented approach is suitable for multi strip mosaicing of satellite data, which operates in step-and-stare mode of imaging. The method is dependent on

(a) Correct identification of features (RCPs) in the overlap region, which is done using image correlation; and

(b) Characterization of estimation errors in the overlap region.

A blunder detection algorithm should be used to eliminate wild points, which get introduced due to mismatches or false correlations. In the current approach, fifth order polynomial was used for characterization of the estimation errors and also for elimination of wild points. It is successful even with homogeneous regions in the image and has a very high success rate.

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6. References

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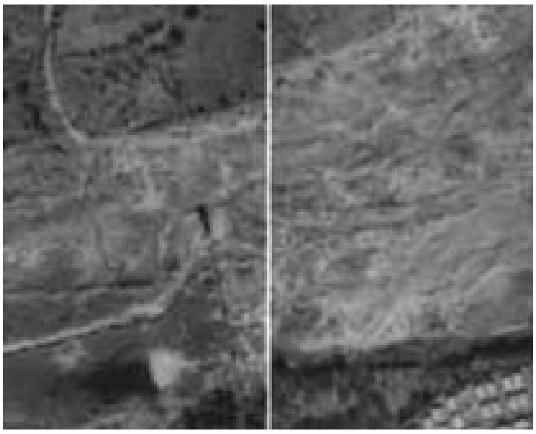
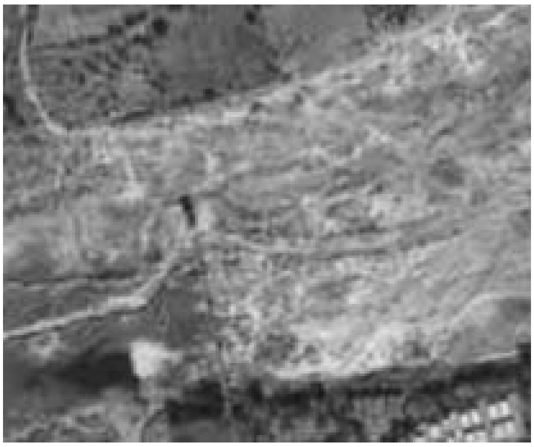
Files placed side-by-side showing feature misalignment.	***Mosaiced***
	
(a)	
	
(b)	
	

(c)

Figure 6