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Automated co-registration of images from multiple bands of Liss-4 camera

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ABSTRACT

Three multi-spectral bands of the Liss-4 camera of IRS-P6 satellite are physically separated in the focal plane in the along-track direction. The time separation of 2.1 s between the acquisition of first and last bands causes scan lines acquired by different bands to lie along different lines on the ground which are not parallel. Therefore, the raw images of multi-spectral bands need to be registered prior to any simple application like data visualization. This paper describes a method for co-registration of multiple bands of Liss-4 camera through photogrammetric means using the collinearity equations. A trajectory fit using the given ephemeris and attitude data, followed by direct georeferencing is being employed in this model. It is also augmented with a public domain DEM for the terrain dependent input to the model. Finer offsets after the application of this parametric technique are addressed by matching a small subsection of the bands (100×100 pixels) using an image-based method. Resampling is done by going back to original raw data when creating the product after refining image coordinates with the offsets. Two types of aligned products are defined in this paper and their operational flow is described. Datasets covering different types of terrain and also viewed with different geometries are studied with extensive number of points. The band-to-band registration (BBR) accuracies are reported. The algorithm described in this paper for co-registration of Liss-4 bands is an integral part of the software package Value Added Products generation System (VAPS) for operational generation of IRS-P6 data products.

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1. Introduction

1.1. Co-registration schemes

A continuous and automated co-registration and geo-location of image data from multiple bands of Liss-4 camera is one of the basic requirements of IRS-P6 data processing. Slight difference in viewing geometries and other inconsistencies at the time of imaging presents an interesting challenge to this requirement. Binding of these bands with spatial correspondence in image locations should be done at the sub-pixel level. Co-registration between the bands can be achieved through image-based or geometry-based methods. Co-registration using the imaging geometry and auxiliary data is achieved indirectly by registering each band to a common coordinate system on the ground. Theiler et al. (2002), explain automated co-registration of Multi-spectral Thermal Imager (MTI) bands using photogrammetric methods. They have also reported the automated image registration of MTI imagery through entirely image-based methods. Initially these two approaches were developed as parallel methods for co-registration and later they were combined into a more hybrid approach (Pope et al., 2003). Co-registration and in-flight calibration updates of MISR (Multi-angle Imaging Spectro Radiometer) imagery are explained by Jovanovic (2002).

The image-based method does not require the knowledge of satellite position and orientation. As the motion of the spacecraft is relatively uniform, the image-based approach generally produces reasonable co-registration in images over plain terrain. In this method, registration of two images is achieved by identification of conjugate points through matching with which a transformation is fitted to rotate one with respect to the other. Image-based approaches involve heuristics about the widow size, similarity measure etc. They work better over images of small sizes like sub-scenes (23×23 km) where terrain undulations are not rapid. The process will become very slow when the window sizes are made wide. They are likely to fail when larger areas with undulations over terrain are considered, where matching widow ranges are not good enough to accommodate the offsets. Also, the change in reflectance between the extreme bands gives only few conjugate points after matching, so that warping becomes impossible in many cases. Thus, image-based registration techniques using cross-correlation are likely to fail with images over hilly terrain, containing snow, cloud and areas without many man-made and natural features. These methods either interactive or automated image matching, though do not require any knowledge about satellite orientation or internal geometry of optics, cannot become a better choice for this purpose.

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Therefore, the development of an automatic registration method for different bands, benefiting from the same orbit acquisition and imaging geometry is essential. Taking advantage of the information of the camera and the satellite, a ground processing makes the estimation and correction process much simpler to achieve even to sub-pixel level co-registration. The software collates the output of all the bands into a spatially consistent multi-spectral image cube where a given location on the ground corresponds to the same position in the image for each of the spectral bands. This is done by aligning the spectral bands to a common grid that is defined in terms of coordinates on the ground. A digital elevation model is used to correct the perspective shifts due to the combined effect of terrain height and view angle of the imaging platform. Direct georeferencing approach is done initially for performing the co-registration task. The major advantage in this approach is its autonomous nature and ability to remove the bulk distortions, which result in mis-registration within the raw data. A validation and fine-tuning of the unaccounted residual offsets are done at the final stage with the help of image-based matching at one or two points to accommodate the bias left if any.

This paper analyzes the effect of various factors on band-to-band mis-registration and explains the development and implementation of an approach for co-registration of multi-spectral bands of Liss-4 within a production environment. We present a geometry-based co-registration approach that accounts for the offsets arising from the imaging geometry and terrain undulations. This method requires extensive information about the satellite position and pointing as a function of time and the precise configuration of the focal plane. These must be combined with the knowledge of the position and altitude of the target on the rotating ellipsoidal earth. Accurate calculation of the exterior orientation parameters with Ground Control Points (GCPs) is not required for this purpose. Instead, the relative line of sight vector of each detector in different bands in relation to the payload is addressed.

1.2. Camera system of Liss-4

From its near polar sun synchronous 817 km altitude orbit, IRS-P6 satellite images with three sensors Liss-4 (L4) Liss-3 (L3) and AWiFS (AWF). Ground Sampling Distance of L4 is 5.8 m (at nadir), L3 is 23.5 m and AWF is 56 m (at nadir). The steerability of the L4 camera, of about $\pm 26^\circ$ relative to the vertical, enables the generation of across-track multi-date stereoscopy from two different orbits. L4 camera uses a staggered array of 12,000 detectors for each one of the three bands. This camera operates in two modes, wide mono and multi-spectral. In the wide mono mode, all the 12,000 detectors (of only one band) will be active and will have a swath of 70 km. In the multi-spectral (MX) mode, only 4200 detectors (out of 12,000) will be active to image a swath of 23 km. Placement of different bands is shown in Fig. 1. The three arrays corresponding to the three bands are physically separated in the focal plane but sharing the common optics. In view of the geometry, the same line on the ground will be imaged by extreme bands with a time interval of as much as 2.1 s, during which the satellite would have moved through a distance of about 14 km on the ground and the earth also would have rotated through an angle of 30 arc s. The multi-spectral bands are separated as shown in Fig. 2 with an angular separation of 0.963° between leading and following bands. A yaw steering is being employed to compensate the earth rotation effects to ensure a first level registration between the bands. This will not account for the factors like orbit and attitude fluctuations, terrain topography, variable offsets between the bands due to the location of the start pixels in the array, Payload Steering Mechanism (PSM) and small variations in the angular placement of the CCD lines

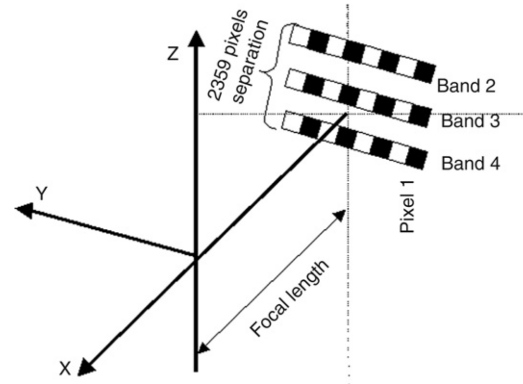

Fig. 1. Detector coordinate system and different bands in the focal plane.

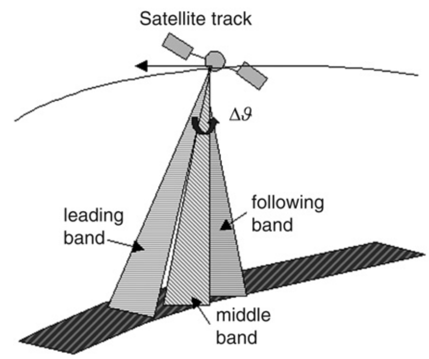

Fig. 2. Multi-spectral imaging of Liss-4 with angular separation $\Delta\vartheta$.

(from the pre-launch values) in the focal plane. Slightly different viewing angles of different bands in combination with the above-mentioned factors could result in a variable offset pattern on the ground. The differences in pixels (across-track direction) and lines (along-track direction) between the images from different bands are not uniform throughout the length of the detector array. These geometric elements and image acquiring modes along with the CCD array switch selection for the start pixel make the multi-spectral data processing a challenge.

2. Effect of various factors on BBR

BBR is of critical importance to the successful generation of data products. Perfect alignment of the bands requires information about the focal plane geometry, satellite orbit and attitude and about the target location. For a push broom sensor like IRS-P6, the largest source of mis-registration is due to uncertainties in the information about the platform during image acquisition. As the ephemeris and attitude are given at an interval of 125 ms, changes in the orbit and attitude behavior within this interval will not get reflected in the navigation data and therefore, cannot be corrected with GCPs. Other factors, which affect BBR, are errors due to inaccuracy in modeling the sensor optics and focal plane and earth's terrain. Finally, the smallest errors are due to modeling the earth's shape, platform jitter and atmospheric refraction.

Orbit determination accuracy of IRS-P6 in the GPS mode is about 10 m and attitude determination accuracy with star sensor in loop is about 202 m. Analysis of the attitude behavior of many datasets reveals that high frequency jitters or disturbances are not present even with high look angles (PSM steering) of the L4 camera. Systematic errors due to the uncertainties in the precise knowledge of position, velocity and attitude will manifest itself only as a bias. But small fluctuations of these parameters that are not reflected in the given navigation data within the time of imaging of

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