Journal of Geomatics Vol. 13, No. 1, April 2019

Spatial enhancement of SWIR band from Resourcesat-2A by preserving spectral details for accurate mapping of water bodies

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(Received: Dec 21, 2018; in final form: Jun 07, 2019)

Abstract: Inland water bodies monitoring using multi spectral images is an important application of remote sensing. Resourcesat-2A (RS-2A) launched on December 7th, 2016 provides data at multi-tier imaging scheme through three instruments viz. AWiFS, LISS-3 and LISS-4 to assess the crop pattern, urban sprawl monitoring, snow and glacier studies, change detection, map land surface water bodies and delineating their spatial distribution to understand the hydrological processes. Short Wave Infrared (SWIR) band from RS-2A LISS-3 sensor is available at best observed spatial resolution of 24 meters and wavelength range of 1.55 µm-1.70 µm plays a vital role for spectral water index determination especially for modified normalized difference water index (MNDWI) which is calculated from green and SWIR bands. The water index accuracy can be enhanced further by improving the spatial resolution of SWIR band from RS-2A platform. In this paper, SWIR band spatial enhancement techniques are described in detail and is divided mainly in two major processing stages. In the first stage, SWIR band spatial resolution is improved directly by combination of laplacian operator to highlight the finer details with smooth gradient to enhance the prominent edges and downscale the image to 12 meters with lanczos based resampling kernel without affecting much the dynamic range of the gray level of SWIR band. In the second stage, spatial enhanced SWIR band of LISS-3 is used for overlap region extraction with same time acquisition data of LISS-4 having spatial resolution of 5 meters and perform weighted average using brovey based image fusion technique to generate SWIR band of RS-2A at spatial resolution of 5 meters by preserving the spectral information. The processing workflow developed can increase SWIR band spatial resolution from 24 meters to 5meters and improve land surface water bodies mapping performance.

Keywords: SWIR, MNDWI, Resourcesat-2A, Spatial Enhancement, Image Fusion

1. Introduction

Resourcesat-2A provides multi spectral images at varying resolution using three cameras: AWiFS at 56 meters, LISS-3 at 24 meters and LISS-4 FMX at 5meters spatial resolution. This multi-tier imaging dataset is potentially important for regional and global water bodies mapping over Indian terrain due to systematic and frequent revisit capabilities. At present, Indian remote sensing data can help us to do routine monitoring for land surface water bodies, which is substantially different from in situ measurements. One of the reliable, user friendly and computationally effective method is Modified Normalized Difference Water Index (MDNWI) proposed by (Xu, 2006) that uses green and short wave infrared (SWIR) bands to enhance water information and can extract water bodies with greater accuracy.

Green band is available by Resourcesat-2A LISS-4FMX camera at a finer spatial resolution of 5 meters. But SWIR band is only available at best possible spatial resolution of 24 meters through LISS-3 Camera. This limitation forces us to improve the spatial resolution of SWIR band at ground for accurate water bodies mapping. In this paper, spatial enhancement techniques are discussed in details to bring the spatial resolution of SWIR from 24 meters to 5 meters. Both spatial interpolation and image fusion methods are applied to increase the spatial resolution of SWIR band. Spatially enhanced SWIR can detect smaller size open water bodies with more explicit and accurate boundaries (Yan et al., 2016).

2. Spatial interpolation for image enhancement

The spatial interpolation is applied to coarser spatial resolution data directly and does not use any additional datasets. The image spatial resolution is improved by applying spatial filters with interpolation kernels in combination to improve the overall spatial information of the datasets. The major steps in spatial interpolation are as follows:

2.1 Image resampling

Resampling is a process that involves the extraction and interpolation of gray levels from pixel locations in the original distorted image and their relocation to the approximate matrix coordinate location in the rectified (corrected) image (Parkar et al., 1983). Image values in non-integer coordinates are computed by lanczos based sinc interpolation kernel.

Lanczos is used as low-pass filter over the remote sensing data to smoothly interpolate the values between its samples. Lanczos kernel is actually a windowed sinc function typically used to resize the digital image and considered to be the “best compromise” among serval spatial filters. In our case, RS-2A SWIR image is resampled to 12 meters using lanczos resampling kernel.

2.2 Spatial filtering

SWIR image at 12 meters’ spatial resolution is improved spatially using image derivative by applying laplacian operator to highlight the finer feature details in SWIR band (Xie et al., 2009). But it also introduces additional noise in the image that is suppressed by applying smooth gradient mask filter that enhance the prominent edges without affecting much the dynamic range of the gray level of SWIR band.

3. Image fusion with LISS-4 FMX

Remote Sensing Image fusion generates single hybrid image from a collection of input satellite images and helps us to extract maximum information from the remotely sensed datasets to achieve optimal spatial and spectral resolution. The image fusion is therefore useful for integrating a high spectral resolution image with high spatial resolution image such as spatially improved LISS-3 data at 12 meters spatial resolution with LISS-4 data at 5 meters spatial resolution to produce high quality and accurate data at 5 meters which contains the characteristic of both the multispectral information (object identification) and the spatial detail (object localization and texture). Image fusion in automatic mode requires sequential execution of different phases for generating quality data products. Digital Image Processing techniques are used to generate fused image in different stages. The main steps/phases involved in image fusion are:

3.1 Geometric transformation

In fusion process, the multi sensor data taken as input have different spatial resolution and generally stored in different projection system. So it is needed to bring the datasets into same projection system and all images are need to resampled to same pixel size using standard resampling technique described in section 2.1. This geometric transformation makes the images ready for fusion to achieve better spatial and spectral characteristics.

3.2 Image registration

Image Registration is the process of aligning different images of the same scene acquired at different times, different viewing angles, and/or different sensors (Misra et al., 2012a). It plays an important role in remote sensing and applied in wide variety of tasks such as image fusion. The image fusion results in science quality data product only when multi sensor data are corrected or modeled for relative geometric error. The feature based image registration techniques are better approach for registering spatially enhanced LISS-3 data with LISS-4 data.

3.3 Image fusion

Fusion described by (Lucien, 2003) as a “formal frame work in which are expressed means and tools for the alliance of data originating from different sources. The integration of low and high resolution optical images from Indian Remote Sensing satellites facilitates better visual and automatic image interpretation that aims at retrieving more information of greater quality. The fusion technique used for merging multi sensor data is color normalized fusion which is a variant of Brovey Transform and has the capability of generating fused product with optimal spectral and spatial resolution.

4. Image fusion methodology

The fusion technique used here for merging multi resolution optical data sets is color normalized fusion which is a variant of Brovey Transform and has the capability of generating fused product with optimal spectral and spatial resolution. Details of this technique are explained further in the following sections.

4.1 Brovey Transform (BT)

The BT uses ratios to sharpen the SWIR image. It was created to produce high-resolution image by merging. Many researchers used the BT to fuse a low-resolution multi spectral band with a high-resolution image. The basic procedure of the BT multiplies each multispectral band by the high-resolution data and then divides each product by mean of the low-resolution multispectral band.

4.2 Color Normalized Transformation (CN)

Color Normalized is an extension of the BT. CN transform also referred to as an energy subdivision transform. The CN transform separates the spectral space into hue and brightness components. The transform low-resolution LISS-3 band with high-resolution LISS-4 FMX data, and these resulting values are each normalized by dividing the mean of the low-resolution multispectral band (Misra et al., 2012b). In the fusion process, a study is carried out to determine most suitable high resolution LISS-4 band by measuring the correlation co-efficient between them and SWIR band of LISS-3. It is noticed that 5m LISS-4 FMX Near Infrared (NIR) band have the greatest correlation coefficient with LISS-3 SWIR and there by chosen as high resolution band for image fusion.

5. Spatial enhancement processing workflow

The processing workflow for improving the spatial resolution of RS2A comprises of two major processing stages. In the first stage, spatial interpolation based image enhancement is carried out that uses the image itself and improve the feature details in the image and generate SWIR band at 12 meters spatial resolution. In the second processing stage, spatially enhanced LISS-3 data is fused with same date acquisition of LISS-4 data on-board Resourcesat-2A platform to generate product at 5 meters spatial resolution. The processing workflow comprises of geometric transformation and multi sensor image registration to make LISS-3 data eligible for image fusion with corresponding high-resolution LISS-4 data. Figure 1 shows the processing workflow developed for SWIR band spatial enhancement.

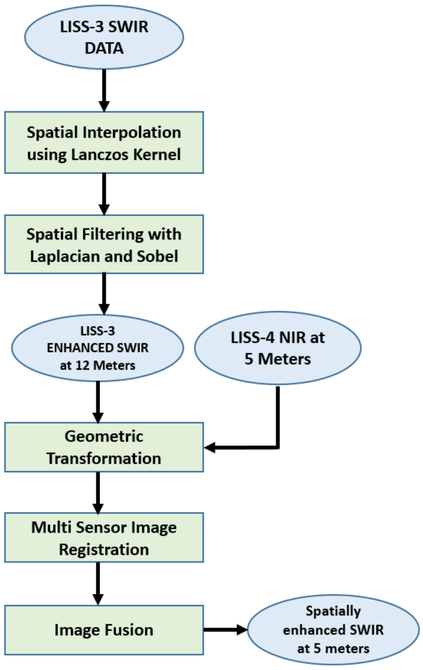

Figure 1: Spatial enhancement processing workflow

6. Results

RS-2A LISS-3 SWIR data is processed using the developed processing workflow. The datasets details is shown in table 1. LISS-3 and LISS-4 same date acquisition data are used to improve the spatial resolution of LISS-3 SWIR band

LISS-3 SWIR data is improved in first iteration using spatial filtering with interpolation technique and downscale the image from 24 meters to 12 meters. Spatially enhanced SWIR at 12 meters along with LISS-4 NIR data at 5 meters is merged to generate SWIR band at 5 meters. Figures 2 & 3 show the SWIR band original, enhanced and finally fused output together to better understand the improvement in each processing stage. In the spatial processing it has been taken care that spectral characteristics of LISS-3 SWIR band should be preserve while improving the spatial resolution.

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Table 1: Spatial enhancement dataset details

Satellite	Sensor	Location	Path/Row	Date of Pass	Map Projection	Spatial Resolution (in meters)
RS2A	LISS-3	Ahmedabad, Gujarat, India	93/56	26 Nov 2017	UTM	24 meters
RS2A	LISS-4			26 Nov 2017	UTM	5 meters

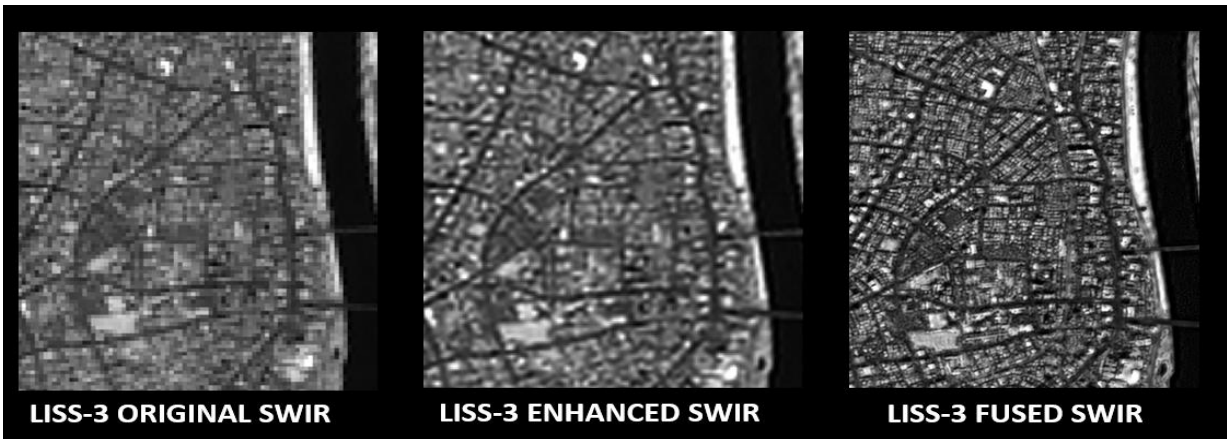

Figure 2: Spatial improvement in LISS-3 SWIR data over Ahmedabad region

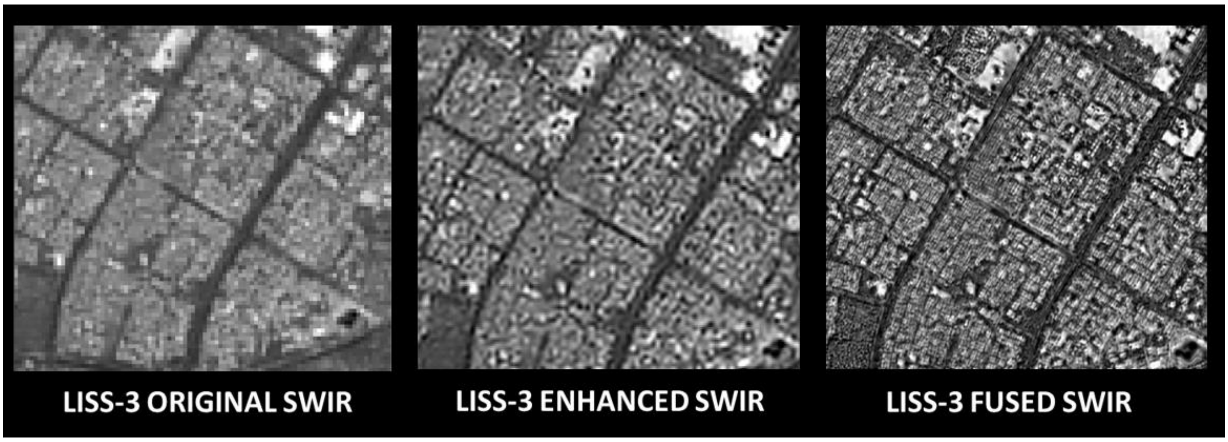

Figure 3: Spatial improvement in LISS-3 SWIR data over Gandhinagar region

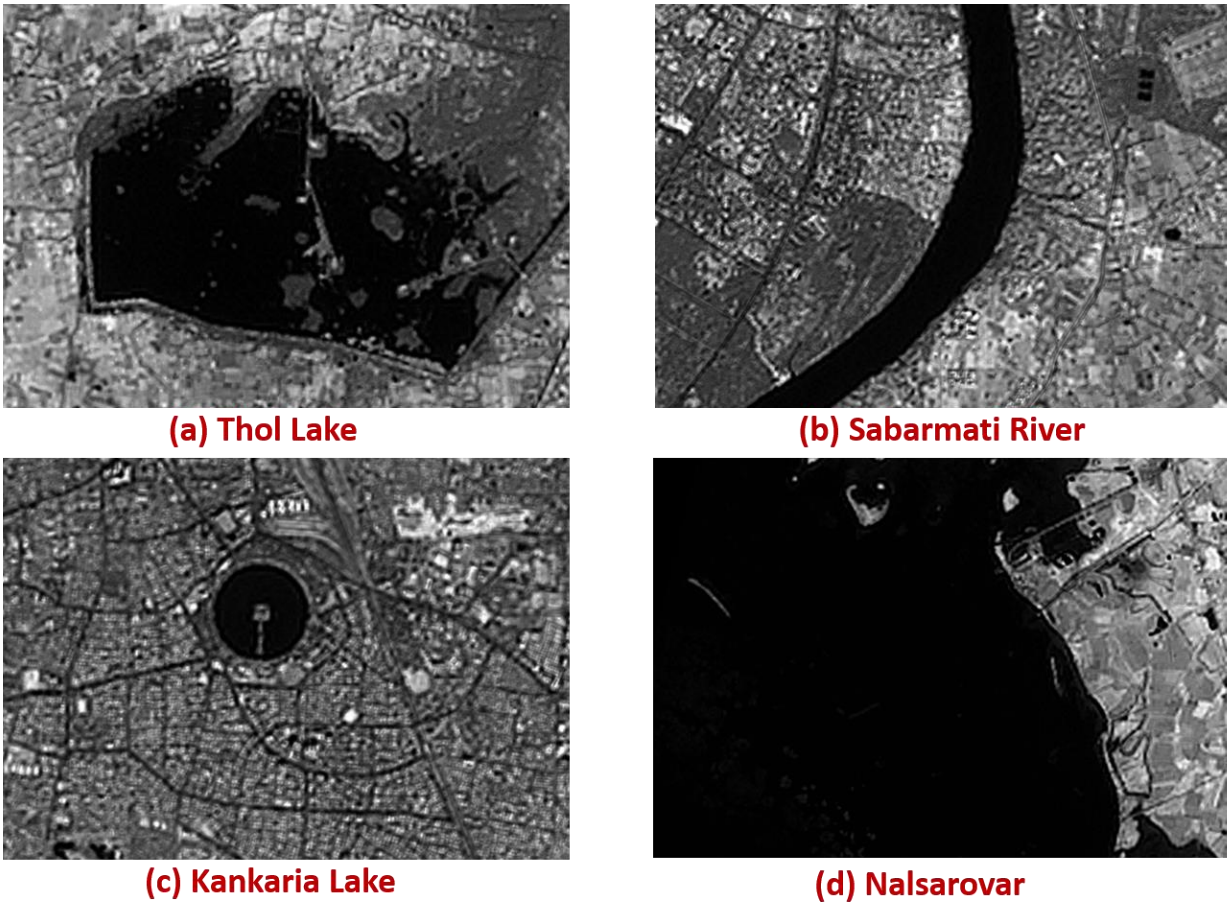

Figure 4: Water bodies of Ahmedabad and its surrounding

SWIR constructed at 5.0 meters need to be compared with original LISS-3 SWIR which is taken as reference for spatial enhancement technique. The original LISS-3 SWIR is at 24.0 meters which need to be cubic interpolated at 5.0 meters for comparison with fused SWIR. Table 2 shows the different image quality metrics (Hore and Ziou, 2010) computed with LISS-4 NIR Band as reference. The fused SWIR at 5.0 meters shows high Signal-to-Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM) and low Root Mean Square Error (RMSE), Mean Absolute Error (MAE) as expected than its original interpolated LISS-3 SWIR. It shows the overall image quality is improved in fused SWIR than its original counterpart.

Quantitative analysis is performed on different water bodies that includes river and lakes. Figure 4 shows some prominent water bodies located in and around Ahmedabad. For assessing the spectral characteristics of fused SWIR, overlap water body region (group of pixels) is extracted from both original SWIR and fused SWIR. The original LISS-3 SWIR at 24.0 meters is radiometrically calibrated and meets the absolute radiometry accuracy specifications. Table 3 shows the average DN count differences between original and fused overlap regions taken from different water bodies as shown in figure 4. The average radiometric accuracy achieved is around 90% with respect to original LISS-3 SWIR which is good enough to map wetland boundaries at better map scale.

Table 2: Image quality metrics comparison between fused and original SWIR

S.No	Test Images	SNR	PSNR	SSIM	RMSE	MAE
1.	Fused LISS-3 SWIR	9.9907	26.1059	0.9981	44.5106	28.9225
2.	Original Interpolated LISS-3 SWIR	8.2663	24.3815	0.9925	54.2853	34.2580

Table 3: Radiometry accuracy assessment table

S.No	Water Body Location	Original SWIR (Avg. DN Count)	Fused SWIR (Avg. DN Count)	Radiometric Accuracy (%)
1.	Thol Lake	10.1	8.8	87.1
2.	Sabarmati River	11.7	10.3	88.0
3.	Kankaria Lake	15.3	14.7	96.7
4.	Nalsarovar	5.4	4.6	85.1

7. Conclusion

Spatial enhanced LISS-3 SWIR band generated can be used for accurate water body mapping by computing spectral water index MNDWI at higher spatial resolution. The processing workflow is tested with multiple cloud free LISS-3 datasets with simultaneous LISS-4 acquisition and looks to provide better accuracy in most of the cases. But also need to see the accuracy of the product for other water bodies such as coastal region and river delta which is not covered in this paper. The future work includes super resolution using single image with deep learning approaches and plug the modules in the existing processing workflow for high quality SWIR data generation.

Acknowledgements

The authors acknowledge Shri D K Das, Director, Space Applications Centre (SAC), ISRO for his encouragement. The authors also thank other team members of optical data processing for their support during the course of work.

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