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Interpolation Of Data Gaps Of SLC-Off Landsat ETM+ Images Using Algorithm Based On The Differential Operators

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Abstract

The scan-line corrector (SLC) of the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor failed in May 2003, and this abnormal functioning of SLC resulted in about 22% of the pixels per scene without being scanned. By filling the un-scanned gap by a good technique will help in more use of ETM+ data for many scientific applications. While there have been a number of approaches developed to fill in the data gaps in ETM+ imagery, each method has shortcomings, especially they require SLC-on (images acquired before SLC-off anomaly) imagery for the same location to fill the gaps in SLC-off (images acquired after SLC anomaly) image. To overcome such shortcomings this study proposes an alternative interpolation method based on the partial derivative. This case study shows that this technique is very much useful to interpolate the missing pixel values in the SLC-off ETM+ data.

Key words: Scan line corrector, Landsat ETM, data gaps, Linear histogram matching, Partial derivative, Kriging

1 Introduction

The malfunction of the scan-line corrector (SLC-on May 31, 2003) of Landsat Enhanced Thematic Mapper Plus (ETM+), resulted in the acquisition of data sets with the gaps ranging from a single pixel (at image-nadir), to about 12 pixels in the satellite scene.[1, 2].It was estimated that on an average about 22% of the total data are un-scanned in each scene showing physical gaps representing missing data in the form of dark line strips [1, 3 and 4]. In addition, the un-scanned portions of the image are not similar in all the spectral bands. There is variation in the process of un-scanning for each band, resulting in few areas scanned in some bands and un-scanned in others

[5].The non-identical un-scanned area in different bands may pose a problem while identifying and filling the data gaps.

Since Landsat data are freely available and many researchers globally depend on this data for their research activities, United States Geological Survey (USGS) team in collaboration with the National Aeronautics and Space Administration (NASA) developed various techniques to fill the data gaps in the ETM+ images [6]. One of the methods developed was Local Linear Histogram-Matching –LLHM [7], where a localized linear transform was done in a moving window of each missing pixel throughout the data gap region to get the rescaling function. This rescaling function along with radiometric values of the input images is used to calculate the value of the missing pixel [8]. USGS/NASA selected this method because it is simple, easy to implement and estimates most of the missing values accurately. However, the method performs well for the input images with minimum cloud, snow cover or fires, low temporal variability with less relative time in target image and input image, and have similar seasonal environmental conditions [9]. Although the method works well in homogenous regions like agricultural fields, but failed in case of intermittent data, such as clouds, snow cover, or fires [7, 8]. Thus, to overcome the limitations of this method alternative techniques were explored.

Researchers [2, 9, 10, and 11] proposed alternative method of using information from the other sensors (Non-Landsat) that has analogous spectral bands with the Landsat-7 ETM+. However, Non-Landsat sensors are constrained with the spectral and spatial compatibility [9]. MODIS has equivalent spectral bands to ETM+ but has a low spatial resolution (e.g. 250 m, 500m) and in spite of this variation, Roy et al [9] made an attempt to use this sensor data to estimate the missing pixels in the SLC-off images.

The multi-scale segmentation approach developed [12] to interpolate missing pixel values in the SLC-off images of a Landsat ETM+ sensor worked well for a variety of applications [13]. However, this method too has a few shortcomings like having lower reflectance prediction accuracy at the pixel level, particularly for small objects, such as roads and streams [5, 12].

The Geo-statistical interpolation methods have also been developed [1, 3] where variogram, a Geo-statistical measure is used for filling the data gaps. Variogram provides the information about the pattern of spatial variability [14] and is used to measure and model the spatial correlation of the pixel values in the image [15]. The variogram models of spatial correlation were then used along with ordinary kriging or cokriging techniques to approximate the un-scanned region in the ETM+ imagery [1]. However this method doesn't work well for small and discrete objects owing to low prediction of pixel reflectance value and are computationally intensive, limiting their execution for mass production [3].

A simple and efficient approach based on the assumption that neighboring pixels have similar spectral characteristics was developed [16] to fill the gaps. Results show that this algorithm estimates missing pixel values with high accuracy and works well in heterogeneous landscape areas [3] in contrast to LLHM method. The method also performs fairly if there is relatively long temporal variation between the target image and input image. But the main disadvantage of this method is that it requires images of the same area as target images when SLC anomaly didn't occur i.e. images before May 2003.

As mentioned above various methods were proposed to estimate the un-scanned areas in Landsat-7 ETM+ imagery and each one has its own merits and drawbacks. For more details on various methods refer [2]. In continuation of research on filling data gaps, in the current study a new methodology is proposed to interpolate the missing pixel values in the SLC-off imagery. This method doesn't require SLC-on images to fill the gaps in SLC-off images like LLHM, NSPI (Neighborhood Similar Pixel Interpolator) and many more other methods.

2 Materials And Methods

A. Data Specification

Landsat ETM+ SLC-off data of 20th February, 2005 with 432 band combination of North Andaman Island was used as sample data in the current study. To validate the proposed method we have also used SLC-on ETM+ image of 15th February, 2003, of the same area.

B. Methodology

The proposed method approximates the missing pixel values in the SLC-off imagery of ETM+ data using the fourth order differential operator. This algorithm uses a least squares approach, but does not make any modification to the known pixel values. Neighbor (pixel which participates in estimating the unknown pixel value) is considered as shown in Figure 1 (a). where black (center) pixel represent the un-scanned pixels and all red pixels represent neighbors of black pixel.

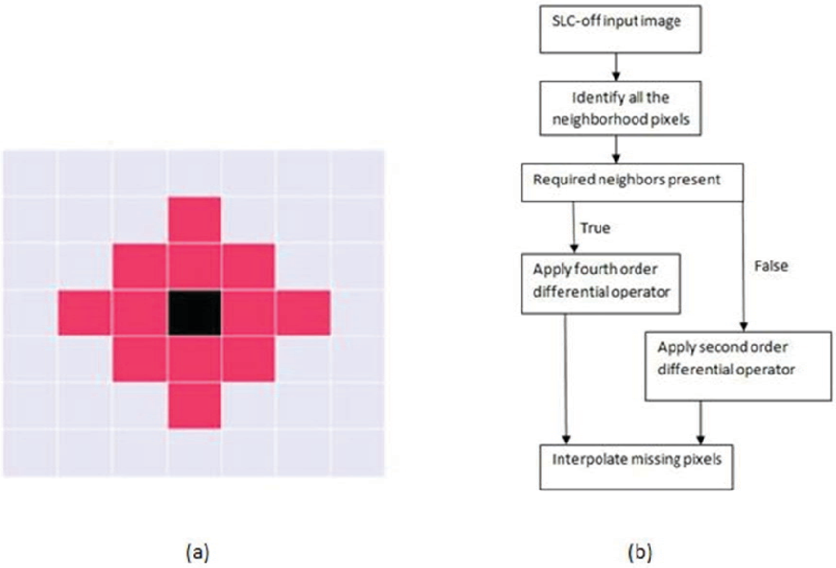

Figure 1. Algorithm used in the current study

The flowchart Figure 1b. shows the steps that are performed to apply the proposed algorithm on SLC-off input image. First neighbors are found out for all the pixels in the image. There are total 12 neighbors considered for each pixel. However 12 neighbors are not possible for all the pixels, for e.g. pixels which are near to boundary does not have all the required neighbors. In such cases, instead of applying fourth order differential operator a lower order differential operator is applied and in this study second order differential operator is taken as a lower order differential operator. To remove the extra computation those pixels are not processed which are not in contact with any missing pixels or in other words, we drop a pixel if this it is not in the neighborhood of any missing pixels.

3 RESULTS AND DISCUSSIONS

A. Results

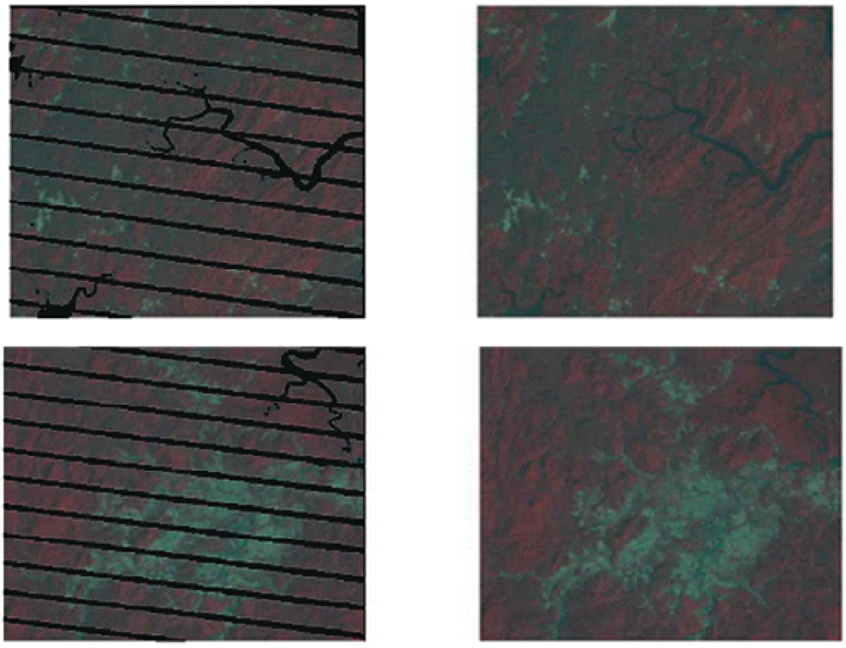

Figure 2. SLC-off images (left), images after filling gaps (right)

Figure 2, shows the performance of the proposed algorithm. All the input images (left image from each set) are SLC-off ETM+ 2005 images and images on the right are the output of corresponding left images after applying proposed method. To prove the correctness of the algorithm, missing pixel values estimated by proposed method are compared with the truth (SLC-on ETM image of 15th February 2003). There are no clear visual differences observed between interpolated and known pixels. A statistical comparison of the results of the proposed algorithm with the truth (original SLC-on images of 2003) is shown in Table 1

B. Validation

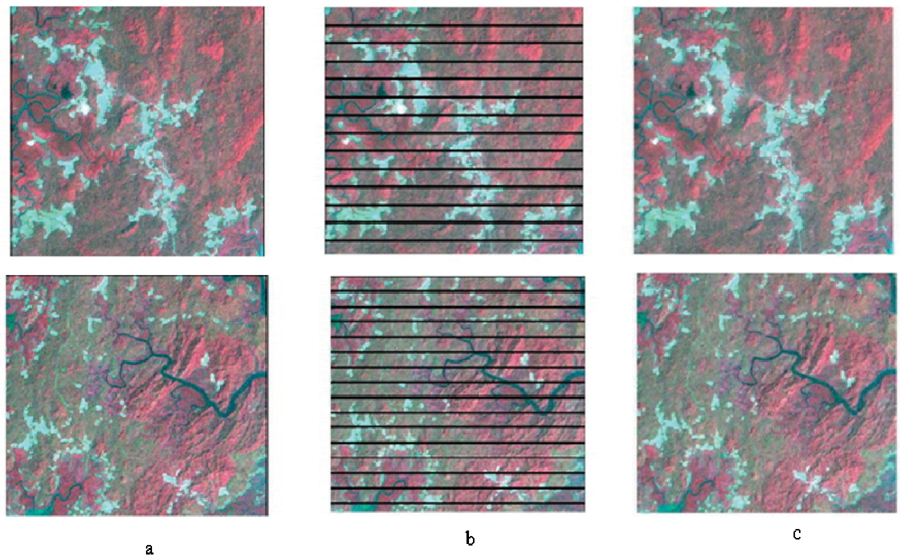

Figure 3. Validation of proposed method – a. SLC-on 2003 images b.Artificially created data gaps in SLC-on 2003 images c. Filled data gaps using proposed method

To further validate the proposed method, we purposefully introduced data gaps in the SLC-on images (acquired in 2003) and run the algorithm. In Figure 3. first column of images is original SLC-on images of 2003 and the second column of images are obtained using first column images by inserting black lines (data gaps) to make it similar to SLC-off images for validation purpose. Thus the algorithm was run on the second column images (created SLC-off) to obtain third column images after interpolation by the proposed algorithm.

Although the interpolation techniques obviously cannot perfectly estimate the unknown pixel values in the image, the resulting image after applying interpolation have good continuity and accuracy. The summary statistics, histograms and distribution of the errors demonstrate that the partial derivative interpolation techniques give good and accurate results. While there are still some minor differences or errors as compared with the known pixel values area, such differences are typically small and within the acceptable error limit of variability similar to the most of the image classification techniques.

4 CONCLUSIONS

In spite of the irregular functioning of the SLC, the radiometric and geometric characteristics of the Landsat 7 ETM+ imagery are widely used in the generation of various thematic outputs. The use of data is more pronounced if the data gaps are removed or filled using different techniques. However, each method has its benefits and drawbacks and current research should focus on developing a better method that has universal feasibility over all the methods implemented so far. The present work attempts to propose a new technique of filling data gaps using differential operators. The use of fourth order differential operator proved to be one of the better and simpler alternative methods in interpolating the data gaps of an SLC-off ETM+ image and the interpolated pixels are at considerable approximations of the original ones. It seems that this technique of filling gaps in the Landsat 7 ETM+ data has great promise.

Table 1. Comparison of the results of the proposed algorithm with the truth

	Original	Output	Original	Output	Original	Output
Image-2	130.6221	131.3382	126	126	125	125
Image-3	128.4788	128.7934	113	113	92	92

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