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SURVEY ON GAP FILLING ALGORITHMS IN LANDSAT 7 ETM+ IMAGES

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ABSTRACT

In remote sensing images the gapping is a known phenomenon. There are several reasons for image gaps, e.g. shadowed area for SAR data sets, cloud coverage for optical imagery and instrument errors such as SLC-off failure. On May 13, 2003 the Scan Line Corrector (SLC) of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor failed permanently causing around 20% of pixels per scene not scanned which become an obstacle and limitation for scientific applications of Landsat ETM+ data. Therefore, reconstruction of gap regions is an important issue in remote sensing image processing. This paper presents an inclusive review of methodologies that have been used to recover the gaps in Landsat7 ETM SLC-off images and the studies have been performed in this area. Then, the paper presents the derived conclusions and the directional to more efficiently researchs on Landsat7 SLC-off reconstruction.

Key words: *Satellite Imag***e,** *Gap Filling, Landsat7 SLC-Off, Image Reconstruction.*

1. INTRODUCTION

Landsat: is a satellite series that uses remote sensing to observing the earth and taking images of the landscape of the world. The radiometers instruments aboard satellite measuring then processing the electromagnetic energy reflected and emitted from the Earth's surface and transmitted through the atmosphere to produce satellite images [1]. The Landsat series is one of the major forces leading to the development of the global earth systems science concept[1],[2].

Since four decades (1972) Landsat program has provided calibrated high resolution multispectral data of the Earth surface on global basis.Because its images are with perfect quality, Landsat imagery provides a unique resource for researchers and common users in evaluation and monitoring agricultural and geological survey, global change detection, archaeology, mapping, water management and regional planning[3],[4],[5].

Until now, the sensors of Landsat satellite consists of the Landsat1-5 Multispectral Scanners (MSS), the Landsat 5 Thematic Mapper (TM) and the Landsat 7 Enhanced Thematic Mapper Plus (ETM+)[6]. Presently, Landsat 5 and Landsat 7 are still being used in orbit for data collection but with advancement of 7ETM+ over TM sensors in improving the spatial resolution of the thermal band6 from 120 m to 60 m and the addition of a panchromatic band with a spatial resolution of 15 m[7],[8]. The spatial resolution of the ETM+ multispectral bands is 30 mand the ETM + sensor passes over every location on Earth every 16 days with a narrow15° field of view [5].

The Scan Line Corrector (SLC), is an electromechanical device on board Landsat-7 designed to compensate for the forward motion of the satellite during ETM+ scanning, has failed permanently on May 31, 2003 leaving an ultimate result is that approximately 22% of scanned image data lost [9],[10]. The un- scanned area are arranged spatially as systematic, diagonal striation that leave large wedge-shaped gaps which range from a single pixel in width near the center of the image to about 14 pixels width towards the edges of the scene. In addition, the gaps shift positions slightly with spectral bands, resulting non- identical areas that have missing pixels across all multi spectral bands with valid data in some bands and no data in others[10],[11],[12], so, the images which acquired before the failure of SLC are designated **SLC-on** images and those acquired after the failure of SLC are designated **SLC-off** images[13]. In spite of the SLC failure produces, obviously

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negative impact on Landsat 7 ETM+ imagery, fortunately, the SLC failure had no effect on the radiometric and geometric quality of ETM+ sensor and about 80% of pixels in the image scanned perfectly. So the ETM+ still significant for some applications and for users over other costly alternative [6],[8]. The rest of this paper is organized as follows. Section 2 briefly describes the gaps filling algorithms including the basic methodologies and approaches. Section 3 introduced the derived conclusions followed by the summary in section 4.

2. GAPS FILLING ALGORITHMS

In spite of malfunction of Landsat 7 imagery, the SLC-off images retain its significant utility for scientific research and application. Therefore in the literature many methodologies have been proposed to resolve SLC-off problem by finding suitable algorithms to estimate the reflectance values at un-scanned pixels accurately and robustly [14]. Generally the gaps filling algorithms are categorized into two main groups, single source method and multi-source method.

2.1 Single Source Method

In this category the reconstruction of the gap area is interpolated using non gapped areas within the same Landsat 7ETM+ fault image itself.

2.1.1 Simple interpolation: The simplest case is replacement the missing pixel value by value extracted from neighboring pixels or from the average of the surrounding pixel values. Nearest neighbor, bilinear, bicubic and other interpolation methods are used for filing gaps in ETM+ SLC-off images using weighted average of appropriate window (e.g. 2x2 in bilinear and 4x4 in bicubic). In general the performance of such interpolation algorithms was inaccurate in spite of their simple and easy implementation because the interpolated value was calculated from pixels surrounding the gap locations rather than estimated the reflectance of land [4].

2.1.2 Spectral interpolation: To interpolate the image gaps using coincident spectral data from the SLC-off image itself, the multi scale segmentation model derived from complete satellite images (Landsat 5 or SLC-on) was overlaid on SLC-off image, then the missing data were estimated using the spectral data on SLC-off that intersect with segment boundary model[15].

Maxwell presented a development of multi-scale segmentation approach for interpolating the ETM+SLC-off images depending on three assumptions related to segmentation based algorithm:

1- The spectral value of adjacent pixels is probably same more than non- adjacent pixels.
2- Pixels have similar spectral values within a specific landscape unit, like crop, grass fields or group of trees.
3- In general for several years no changeable in small landscape unites.

The quality of the segment model depends on some conditions that available in the image which is used to generate the segment model:

1- The segment image has minimum cloud cover.
2- The image selected with appropriate time of the year (i.e. inappropriate time will not provide precise separation of landscape units).
3- The time interval between segment image and SLC-off image (long time interval, more change in landscape structure).

Three scale segment model (scales 10, 15 and 20), derived from SLC-on image, were used to direct the spectral interpolation over the gaps in SLC-off image. The proposed method applied in three case studies: grassland, cropland and forest landscape. A comparison between original Landsat 5 and filled images was used to evaluate the accuracy of the gap filled technique, the results indicate that most of gap pixels with high accuracy were interpolated using segment model of scale 10, thus the product could be used in land cover mapping (e.g. forest and grass), crop mapping and regional-scale studies. At the same time, at pixel level the accuracy of the reflectance prediction was low especially in narrow and tiny objects as in roads and rivers[5],[13], [16].

2.2 Multi Source Method

In this category, the un-scanned locations values are estimated either using Landsat7 ETM+ images which acquired pre or post SLC failure (SLC-on or SLC-off) or exploiting information from sensors other than Landsat 7 ETM+.

2.2.1 Using multi-temporal Landsat7 data

In multi temporal images (image with near time and same extent), the reflectance of the same location may different although the data acquired from the same sensor. These differences caused from three reasons: first, the effects of the variation in the observed condition which has less influence on imaging process. Second, regular changes in objects and these changes can be predicted using

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auxiliary information. Third, abrupt transformation in the target object that caused by human activities like urban expansion, this difference causes significant spectral changes which are difficult to predict. Therefore the scenes that brought auxiliary data must be chosen as close as to primary scenes date[5].Using multi temporal Landsat7 data to recovering the gaps by forecasting the un-scanned values can be divided into four basic methodologies, USGS/NASA, geostatistical, PCT and NSPI methodologies.

2.2.1.1 USGS/NASA methodology

In spite of the failure of the SLC work which produces clearly negative effects on Landsat 7 ETM+ data and because the radiometric and geometric quality of the acquired images was not affected, the routine ETM+ imaging operations were resumed with SLC failure.The image with SLC-off that chooses to fill the gaps is defined as **primary or target scene** and valid data within the primary scene will be retained, while the image (or images) that chooses to fill in the gaps in primary scene is defined as **fill or an auxiliary image**[17].

Immediately, after the SLC failure the USGS/NASA (United States Geological Survey/National Aeronautics and Space Administration) Landsat team suggested that, the reflectance of missing pixels, at gaps locations, could be predicted by compositing the target images with corresponding band of laterally overlapping ETM+ images, and/or ETM+ images, SLC-off or SLC-on images acquired on other dates for the same area [3],[11].

In October 2003, jointly between USGS Landsat project and NASA Landsat project, an improvement workshop held the development of composite data products that combine an SLC-off image with one or more fill image (SLC-on or SLC-off images) to recover the gaps in SLC-off scene [18]. Expert team from USGS/NASA provided two phases includes techniques to recover gaps in SLC-off images.

Phase 1 produces a simple, easily implemented radiometric adjustment technique to fill gaps in SLC-off scene using data from one scene which acquired prior the ETM+ SLC failure (SLC-on). This phase includes Global Histogram Matching (GHM) and Local Linear Histogram Matching (LLHM) algorithms [19]. The basis of phase1 methods was to implement the radiometric adjustment using linear transform between the SLC-off image (primary scene) and SLC-on image (filled scene) band by band by calculating the corrective gain and bias of pixels in SLC-on image to estimate the pixels values on SLC –off images. Rather than performing a computationally expensive linear fit, the corrective gain and bias are calculated using mean and standard deviation. This algorithms was used between 6/1/2004 to 11/18/2004, before it was replaced by phase2 algorithm [18],[20].

GHM technique: it is the first and basic algorithm proposed to repair the gaps of ETM+ imagery. In this method the corrective gain and bias adjustment was calculated from all pixels of SLC-on image, therefore it perform well in deserts and rocky areas with invariant terrain scene, but visible errors occurred in scene with transient area such as heterogeneous landscape [6],[18],[21].

LLHM technique proposed for greater precision results and better looking by calculating the corrective gain and bias adjustment using moving window around each pixel in CLS-on or another SLC-off image to obtain the localized linear transform function, and then transform the pixel value of SLC-on image to fill in the gapped pixels in SLC- off image. The LLHM method can lead to suitable results when the target and input scene satisfied pre-determined conditions (minimal clouds, snow cover , minimal temporal shift, seasonal differences and minimal date separation), but it has limitation when there were sharp differences in target radiances as a result to atmospheric effects, land cover change, or sun glint change [9],[13], [22].

Phase2 In 11/18/2004 phase2 gap filled product was declared as enhancement to phase1 product techniques, this phase allow the user to using multiple scenes (one or more SLC-off) because the location of gaps differs per images which taken for the same area [17],[20].

In phase2 the Adaptive Window Local Histogram Matching (AWLHM) algorithm was used as improvement to the LLHM algorithm in phas1. The AWLHM based on the same supposition as LLHM with exception in the change of the size of moving window. For each moving window the gain and bias were found statistically from effective pixels that was used for estimating each un-scanned pixels, the size of moving widow changed depending on the distribution of commonly scanned pixel. The improvement of AWLHM in that when

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there were still un-scanned pixels in target image, the recovering algorithm could be repeated for several times by assigning the last recover image as a target image and taking other fill image[6]. The results of AWLHM was more rational as compared with GHM and LLHM, especially in homogeneous area where the adjust temporal changes was happened as in agricultural fields, but it has difficulty to get suitable results when significant changed occurred in areas smaller than the local widow size [6],[17]. Some comparative studies have been done depending on phase 1 and phase2 algorithms.

Hu used multi temporal images to reconstruct SLC-off ETM+ images by applying the Local Correlation Analysis approach (LCA) on simulated and real SLC-off ETM+ images and compare the results with applying the LLHM method on same tested images.Visual and statistical indices indicated that the LCA approach filled image coincided well with the target image and also preserving the spatial continuity in vegetation and soil land cover[4].

Ali & Mohammed compared single source gap filling algorithms (mean, median, mid-point and some interpolation algorithms) with the LLHM approach which calculating the mean and standard deviation using the whole image values firstly, and appropriate window's values secondly. Although LLHM method yields a better gap values interpolation than other methods, there were still some margin pixels had not filled because the large size window has skipped them[12].

Also, some studies were developed to reconstruct the large gaps in 7ETM+ SLC-off images using USGS methodology, He presented a comparative study on repair the ETM+ fault image in simulated gap image derived from SLC-on image using number of basic regression gap filling algorithms, GHM, LLHM, AWHM and adaptive window regression algorithms. In GHM two types of matching were used; matching based on average and matching based on mean and variance. The simulated image consists of three types of gaps: internal gaps with single width, edge and internal gaps with 14 pixel width. Objective comparison was derived from RMSE and the results show that adaptive window regressions algorithm was suitable to restore the internal gaps with 1 pixel width while the GHM algorithm was effective with large width gaps depending on amount of data, with a large amount of data the GHM repair algorithm based on mean matching was used and when less amount of data the GHM repair algorithm based on mean and variance matching was applied [21].

In case of large gaps (14 pixels wide), when recovers the center pixel the algorithm depends on the results of recover algorithm in the previous step and this will increase of interpolation errors, therefore the values obtained in this case cannot substitute real land cover.

Rulloni presented and compared (in the same case study) three imputation methods to recover large gaps in Landsat 7 SLC-off ETM+ image using accurate temporally extra information which derived from the lower resolution sensor. Method A, based on merging information of target and low resolution image in Foriour domain. Method B, low resolution extra data are used in linear regression model and method C, generate map of classes from primary segmentation method, then radiometric imputation was made by assigning a random value from convex hull made by the neighbor pixels within the class. Four performance measures were used to assess the accuracy of the results, Kappa and Overall Accuracy were used to assess the segmentation accuracy and Q-coefficient, RMSE were used to measure the radiometric interpolation accuracy. Statistical results indicate that method B had significant performance over A and C methods but with loses sharpness and appear slightly blurred [23].

2.2.1.2 Geostatistical methodology

Depending on the geography law, the spatial data values that are close to each other are more similar than that distance data values, geostatistical techniques were designed for spatial data by exploiting spatial correlation information to predict the missing values of SLC-off ETM+ images. Variogram is a geostatistical measure which provides a brief description of the pattern of the spatial variability by relates variance with spatial separation[10],[11].

Zhang presented spatial interpolation approach, geostatistical algorithms, that effectively estimate and filled data gaps in ETM+ imagery using digital prediction extract from digital number values within the same data set of the gaps, ordinary kriging and standardized ordinary cokriging were used to estimate digital number values, using variogram to characterize the spatial structure and measure the spatial correlation, in order to fill the gaps in ETM+ image. While ordinary kriging used the information derived from target SLC-off image

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to predict the un-scanned values, standardized ordinary co kriging was used when the variable to be predicted were spars and there were abundant in samples of second related variables.

Although, geostatistical interpolation methods were suitable for many applications, such as evaluating of mapping in large scale landscape area where rapid seasonal changes take place, these methods could not predict the reflectance well at a pixel level, therefore, the accurate prediction was difficult at the junction of different lands and in linear features, such as rivers were filled as land surface and roads filled as other landscapes also geostatistical methods were limited in their implementation for mass production because they were very computationally intensive[5],[11],[24].

Pringle using the information extracted from three close interval time Landsat ETM+ SLC-off image of the same scene to predict the reflectance values at un-scanned locations (in the middle image) by using a Co kriging algorithm with secondary information from the earlier and later images and return to the kriging method when there was not enough information in secondary images. In this paper seven estimators were used: Three Compositing methods: simple composite M1, composite with local mean and variance correction M2 and composite with global mean and variance correction M3. In addition to two geostatistical interpolation method (kriging and cokriging) M4, three hybrid estimator (one of compositing method followed by M4) $M_{1,h}$, $M_{2,h}$, $M_{3,h}$ were proposed. Two assessment indices were used to validate each estimator: Concordance Correlation Coefficient was used to assess the accuracy, while RMSE was used to evaluate the precision of interpolation. The results show that the accurate prediction of all un-scanned pixels with geostatistical method while the disadvantage was appeared in difficult accurate prediction at junction between lands and slow speed [10].

2.2.1.3 PCT methodology

Boloorani using a multispectral projection transformation based on (Principal Component Transformation) PCT gap filling algorithm to reconstruct a simulated gapped area in Landsat 7 ETM+ imagery using valuable pixels from earlier obtained ETM+ as auxiliary image and compared the results with a commonly USGS algorithm (LLHM). The maximum likelihood classification was used to classify the reconstructed area, then post classification accuracy measurements (overall accuracy and Kappa coefficient) were used to evaluate the quality of the technique, furthermore statistical indicator, Universal Image Quality Index (UIQI), and visual inspection also used in the comparison with LLHM method. The results indicate the superiority of PCT over LLHM in preserving the radiometric characteristic of multispectral data and usefulness for land surface classification and local cover mapping. In the same time there were still visible gap lines with sharp radiometric differences areas[9].

2.2.1.4 NSPI methodology

Because the previous methods have shortcomings, especially for heterogeneous landscapes, J. Chen proposed a simple and effective method for filling the gaps in Landsat ETM+ SLC-off images using suitable and related information of neighboring pixels located close proximity to the un-scanned pixel. The Neighborhood Similar Pixel Interpolator (NSPI) based on two assumptions: first, the neighboring pixels within the same class around the un-scanned pixel have similar spectral characteristic and second, the un-scanned pixels and its neighboring exhibit similar pattern of spectral differences between dates. Single and multiple auxiliary intensive fill images (consist of homogeneous area such as water cover and heterogeneous area such as forest and arable land) were used to fill gaps in simulated and actual SLC-off target image, depending on the above assumption the values of un-scanned pixels can estimated using weighted linear model from its neighboring similar pixels. Root Mean Square (RMSE) and Average Differences (AD) metrics were used to assess the characteristics of filled images using NSPI and LLHM methods. The results indicate that NSPI can predict the un-scanned pixels very accurately over LLHM, particularly in heterogeneous landscape and even when there is a long time interval between fill and target images [13]. Although the superior of NSPI algorithm in recovering heterogeneous landscape and the spatial continuity of the filled images can be retained even using the auxiliary image with long time interval, it cannot produce statistical uncertainty of prediction [25].

Zhu presented an improvement of NSPI algorithm using geostatistical theory which called Geostatistical Neighborhood Similar Pixel Interpolator (GNSPI) using Landsat 5 TM and ETM+ SLC-off as auxiliary images. Although both of NSPI and GNSPI methods using weighted average interpolator to calculate the un-scanned

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pixel prediction, in GNSPI the weights were calculated depending on spatial dependence of the image using geostatistical theory. The results of GNSPI compared with previous NSPI and geo statistical methods to evaluate the strength and limitation of proposed one. RMSE was used to evaluate the accuracy of the filled images quantitatively and comparison between the land cover maps produced from applying a classification algorithm on actual and filled images were also performed using an overall accuracy (oa) and Kappa coefficient indices. The image filled by GNSPI has fewer striping effects and can provide uncertainty of prediction also the superiority of GNSPI when using temporally further input images because it is difficult, in cloudy region, to get a temporally closer input images[24].

Mohammdy using the same assumption of NSPI algorithm in recoverig SLC-off image on study area in Iran. Furthermore, LLHM approach was applied to predict the remaining un-scanned values. Unsupervised classification was applied on both recovered SLC-off and basic TM images for quantitative evaluation and the results show that the percent area of classes was comparable[26].

Zeng proposed an integrated approach to recover the missing pixels by using a multi temporal algorithm followed by the non - reference approach. Weighted Linear Regression (WLR) algorithm was used to reconstruct the un-scanned locations in a complicated landscape area using an auxiliary information from multi temporal SLC-off images, then the regularization algorithm was used to recover the remaining gaps when the auxiliary multi-temporal information cannot reconstruct all the un-scanned pixels. Simulated and real ETM+ images were used to experiment the proposed method, then compare the results with results of two conventional methods (LLHM and NSPI) which applied to the same tested images. Four statistical indices were used to assess the results quantitatively.

1 - Parson correlation coefficient (r).
2- Average Relative Error of predicted value (ARE).
3-UIQI
4-Mean Spectral Angle (MSA)

Also, after applying maximum likelihood supervised classifier on filled and real images, the classification accuracy was assessed using OA and Kappa indices. The results of the proposed algorithm indicate the accurate prediction of the missing values, especially, in the edges with ability of keeping the shape of the ground features but, when the scenes changed abruptly; the recovered results may be not suitable also the proposed algorithm relatively slow computing speed [5]. Table (1) summarizes the basic methodologies and their advantages and limitations.

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Table1: The Advantages And Limitation of Basic Gap Filling Methodologies

Approach	Single or Multi Source	Advantage	Limitation
Simple Interpolation	Single Source	Simple and easy implementation	Inaccurate results because the gap value calculated from surrounding pixels
Multi-Scale Segmentation	Single Source	Most of gap pixels with high accuracy were interpolated	At pixel level, the accuracy of the reflectance prediction is low
Phase1 (GHM)	Multi Source	Suitable results with invariant terrain scene	Visible error in heterogeneous scene where there were transient areas
Phase1 (LLHM)	Multi Source	Suitable results with predefined condition of minimul cloud, snow and time acquired separation	Inaccurate results when there were differences in target radiances
Phase2 (AWLHM)	Multi Source	Good results in homogeneous landscape	Still, gaps visible when the significant changed occurred in areas smaller than the local window size
Geo statistical methods	Kriging (single source) Co kriging (multi source)	Provide uncertainty of prediction	1-Could not predict the reflectance well at a pixel level 2-computationally complex
Multispectral projection transformation based on the PCT	Multi source	Preserving the radiometric characteristic of multispectral data	Visible gap lines with sharp radiometric differences areas.
NSPI	Single source	1-Recovering heterogeneous landscape 2-The spatial continuity of the filled images can be retained even using the auxiliary image with a long time interval	Cannot produce statistical uncertainty of prediction

2.2.2 Using data from auxiliary images

The performance of the algorithms that used multi temporal Landsat images may be inefficiency if there was a radical differences in target radiance because of presence of clouds or changed in land cover which may occur when the temporal variability was high among the primary image and fill images, therefore an auxiliary information from non-Landsat images with appropriate time acquisition could be used to recovering the SLC-off ETM+ images[14].

In general, using information from other operational sensor on board of other platform, non-Landsat sensors, as fill images is restricted by spatial resolution, spectral compatibility and financial constraints. A few instruments are spectrally similar to ETM+ but most sensors with spatial resolution similar to ETM+ are expensive to obtained[7],[24].

Several studies were proposed by using images from sensors other than Landsat 7ETM+, which their acquisition time was close as possible as the primary SLC-off ETM+ image, to predict the missing values.

Roy show that because the abundant images provided by Moderate Resolution Imaging Spector Radiometer (MODIS) BRDF/Albedo land surface characterization product and although its spatial resolution is more coarser than that of Landsat7 ETM+, the information extracted from MODIS sensor can be used in estimating the missing pixels in SLC-off image using semi physical fusion approach. This approach was simplicity applied on per-pixel basis and was unaffected by the presence of contaminated neighboring Landsat pixels or temporal variation due to surface change. But also there was apparent contradiction of data between MODIS BRDF/Albedo and Landsat7ETM+ besides of another insufficiency related to the need of enough data in geometrical computation and co-registration[27].

Boloorani depending on the knowledge of the statistical structure of the an auxiliary image bands which were used to reconstruct the gapped area in SLC-off ETM+ image, Regression Based Data Combination (RBDC) methods were proposed using the spectral similarity and statistical correlativity between Advanced Land Imagery (ALI) onboard the Earth Observer One (EO-1) data (band 4) and ETM+ imagery (band 3) to reconstruct the gapped in SLC-off ETM+ image. Four

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regression based techniques were proposed and evaluated on the same study area, Scene Based (SB), Cluster Based (CB), Buffer Based (BB) and Weighted Buffer Based (WBB). The accuracy of each reconstructed techniques was evaluated using correlation coefficient R and offset parameter, the results indicated that WBB and CB techniques have suitable results over SB and BB techniques[28].

Reza used IRS/ID LISS-III sensor products to compensate malfunctioning of SLC in the Landsat7 ETM+ sensor in southwest of Iran. The proposed approach divided into two steps. Step1 the gaps in ETM+ images were filled using linear regression model between bands 3, 4 of ETM+ and bands 2,3 of LISS-III to produce two new fill images in band 3,4. Step2 the two reconstructed images (band3, 4 from step1) are used to recover the other spectral ETM+ bands and this consist two methods. Method 1 using linear relation between new ETM+ images (band 3,4) and bands 1,2. Method 2 reconstructed the remaining spectral bands of ETM+ images using planner relationship between reconstructed bands from step1 (3,4) and the remaining bands (5,6, and 7). The proposed approach get fairly results with reconstruction of bands 3, 4, but with remaining bands, the precise of the results was decreased because of using the latest recover bands[7].

Chen exploited the spectral similarity between China Brazil Earth Resources Satellite-02B (CBERS-02B) and Landsat 7 ETM+ to estimate the un-scanned pixels value in SLC-off images. Four popular algorithms were tested (Simple filling gaps, GHM, LLHM and AWLHM) to predict the reflectance of the un-scanned pixels, RMSE and Systematic Error (SE) indicators were used to evaluate the accuracy of the four algorithms. Because in AWLHM algorithm the number of effective pixels and the effect of local conditions were taken into account, the results of applying AWLHM has higher accuracy than other algorithms especially with homogeneous landscape rather than heterogeneous landscape, also the results show that the filling gaps procedure affected by the temporal difference between ETM+ SLC-off and CBERS-02 images [3].

Although most of studies were developed to reconstruct the multispectral bands of images, few attentions has been paid to recover the thermal band which was widely used for scientific applications such as urban heat island, water environment and geothermal exploration. F. Chen presented a methodology trying to predict the un-scanned values in thermal band of ETM+ SLC-off image by choosing suitable combination bands (bands 3 and 4) from CBERS-01 sensor. Two algorithms were used in recovering thermal band in a simulated SLC-off ETM+, AWLHM and modified AWLHM and the accuracy of the results were evaluated by comparing with realistic image using UIQI, RMSE and relative mean error (ME). Although, most part of un-scanned pixels were estimated in unbiased manner as indicated in the results, some of points must be considered when applying the algorithm in area with sharp radiometric changes, and the time interval between the acquisition of auxiliary and ETM+SLC-off images [8]. Table (2) summarizes the studies that used data from auxiliary images rather than Landsat images.

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Table2: The Advantages And Limitation of The Gap Filling Methods Using Data From Auxiliary Images Rather Than Landsat7 Images.

Approach	Type of Auxilixary Image	Advantage	Limitation
Semi Physical Fusion Approach	MODIS	1-Simplicity applied on per-pixel basis 2- Unaffected by the presence of contaminated neighboring Landsat pixels or temporal variation due to surface change.	Need of enough data in geometrical computation and co-registration
Regression Based Data Combination (RBDC)	ALI/EO-1	WBB and CB techniques have suitable results over SB and BB techniques	Limitation in homogeneous landscape
Linear Regression Model	IRS/ID LISS-III	Good results with reconstruction of bands 3, 4.	The precise of the results was decreased in bands (5,6 and 7) because of using the latest recover bands.
Simple filling gaps, GHM, LLHM and AWLHM	CBERS-02B	Higher accuracy, especially with homogeneous landscape	Low accuracy in reflectance prediction in heterogeneous landscapes
Thermal band	CBERS-01	Most part of un-scanned pixels were estimated in unbiased manner	Shortcoming in areas with sharp radiometric changes

3. CONCLUSIONS

Various gaps filling methodologies for Landsat7 ETM+ were suggested and introduced; in general, there are single source and multi-source methods, for each method with different methodologies, some conclusions can be derived:

In single source the simple interpolation techniques are simple and easy to implement, but with inaccurate results because the interpolated values extract from pixel values surrounding the gaps location rather than the estimation of the reflectance value while in multi scale segment approach, although the gaps locations were interpolated from the values in the image itself but it constraints with the object borders of the land surface extract from other images. The results show that the approach was useful in general land cover mapping, but it was not recommended for per-pixel applications such in urban areas.

Because images acquired for the same area on different dates by Landsat7 sensors have random un-scanned locations, several techniques were introduced with selecting cloud free and close time interval SLC-off or SLC-on images to restore other SLC-off images. GHM, LLHM and AWLHM were conducted in phase1 and phase2 products, both LLHM and AWLHM technique can yield good results in homogeneous regions, but also with poor results when the size of the surface objects in reconstructed area smaller than the local moving window.

Spatial interpolation methods were proposed depending on geographic law and geostatistical measure, variogram, to estimate the values of un-scanned locations and also quantified the uncertainty of prediction. Kriging and standardized ordinary co kriging were used to estimate the un-scanned values in Landsat7 ETM+ imagery using SLC-off or SLC-on with co kriging approach. Geo statistical algorithm's performance better than LLHM in target images with radical differences in radiance, but also at pixel level the reflectance could not predict well, therefore they were not optimal reconstructed methods for small and discrete objects and they also relatively slow in computing speed.

To improve the recovering methods in heterogeneous landscapes, NSPI algorithm was proposed to integrate the spatial and temporal information of input image in prediction of the un-scanned values. NSPI provides more precise results in tiny and tight features even when using auxiliary images with a long time interval but at the same time it could not provide uncertainty of prediction.

GNSPI was proposed to improve the accuracy of gap filling over both geostatistical and NSPI methods by calculating the weighted average depending on spatial dependence of target image using geostatictical theory. The results indicated the robustness of GNSPI when the input images acquired in long interval time.

Because it is difficult to get SLC-on or SLC-off fill images with restricted requirements, an alternative fill image from other sensors instead of ETM+ was possibly used for recovering the SLC-

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off ETM+ image, but with take into account spatial resolution similarity, spectral concords, and time of acquisition. Information extracted from several sensors, MODIS, ALI/EOI, IRS/ID LISS-III and CBERS-02B, were used to reconstruct the gaps in SLC-off ETM+ images. Always, the filling gap approaches are operating band by band and because the number of similar multispectral bands provided by using sensors are less than that in ETM+ sensor, therefore this causes limitation in using these products in reconstruction procedure.

4. SUMMARY

In this review paper, we attempted to introduce some of popular recent research works conducted on Landsat7 SLC-off image reconstruction. Through the analysis of these literatures works, we can conclude that it is necessary to understand the pattern of spatial variability in Landsat7 ETM SLC-off remotely sensed images and quantified the uncertainty of prediction for accurately estimate the reflectance of the missing pixels especially in a heterogeneous landscape where there are small and discrete objects.

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