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Recovering of the thermal band of Landsat 7 SLC-off ETM+ image using CBERS as auxiliary data

Feng Chen [a,b,*], Lina Tang [a,b], Cuiping Wang [a,b,c], Quanyi Qiu [a,b,c]

[a] Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China
[b] Xiamen Key Lab of Urban Metabolism, 1799 Jimei Road, Xiamen 361021, China
[c] Graduate University of the Chinese Academy of Sciences, 19 Yuquan Road, Beijing 100049, China

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Abstract

The failure of scan-line corrector (SLC-off) has resulted in the limited use of Landsat 7 ETM+ images. Considering its characteristics, many attempts have been conducted to recover the SLC-off ETM+ image. While much attention has been paid to recovering the optically multispectral bands, few researches have been done to reconstruct the thermal band. Main purposes of our study were to evaluate the possibility that using China Brazil Earth Resources Satellite (CBERS) as auxiliary data to recover the thermal band of SLC-off ETM+, and discuss the usage of the recovered one. The adaptive window linear histogram match (AWLHM) method was selected primarily, followed by the modified one. Results illustrated the feasibility of using the modified AWLHM method with the linear combination of CBERS-01 band3 and band4 to reconstruct the SLC-off thermal band. It encourages that further researches should be done to enable more scientific application of SLC-off ETM+, particularly its' thermal band.

Keywords: Recover; Thermal band; SLC-off ETM+; CBERS

1. Introduction

The Landsat Program has provided calibrated high spatial resolution data of the Earth's surface to a broad and varied user community nearly 40 years, including agribusiness, global change researchers, academia, state and local governments, commercial users, military, and the international community (NASA, 2008). Landsat 7 which was launched from Vandenburg Air Force Base on April 15, 1999, has been the latest version of the Landsat series. The Enhanced Thematic Mapper Plus (ETM+) sensor, on board the Landsat 7 satellite, is much advanced than the Thematic Mapper (TM) sensor of Landsat 5, especially improving the spatial resolution of the thermal band from 120 m to 60 m as well as the addition of a panchromatic band. Unfortunately, the scan-line corrector (SLC) for the ETM+ sensor failed permanently on May 31, 2003 (NASA, 2004). As a consequence of the SLC-off problem, approximately 20% of the pixels in an ETM+ image are not scanned, resulting in the limited use of ETM+ data for a certain amount of applications at present. Additionally, Landsat 5 has had problems with its solar array drive which have affected data availability (Furby and Wu, 2009), suggesting that Landsat 5 would be at the end of its operational life and not be reliable on as a source of future imagery (Pringle et al., 2009).

Fortunately, SLC-off has not affected the radiometric and geometric quality of the ETM+ sensor, with about 80% of the pixels in each image being scanned in a perfect way (USGS, 2003). Many attempts have been made to fill the un-scanned pixels, thus to continue the usage of the SLC-off ETM+ images. Methods include the global linear

* Corresponding author at: Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China.
E-mail addresses: fchen@iue.ac.cn, chenfeng105@gmail.com (F. Chen).

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histogram match (GLHM), localized linear histogram match (LHMM), adaptive window linear histogram match (AWLHM).These methods estimate the un-scanned pixels in one SLC-off ETM+ image (the target image) with the corresponding band of the laterally overlapping ETM+ images, and/or ETM+ images of the same area from other close dates (the fill image) (Scaramuzza et al., 2004; USGS and NASA, 2004). The values at un-scanned pixels in SLC-off ETM+ image were estimated reliably through the geostatistical approach (Pringle et al., 2009). Darsishi et al. (2008a) developed a new methodology called 'projection transformation' to fill the gapped area in SLC-off ETM+. As an alternative to these methods, it is feasible to use the information from a sensor other than ETM+ (Reza and Ali, 2008; Darsishi et al., 2008b; Chen et al., 2010). While much attention has been paid to the recovering of the multispectral bands (e.g. visible and near infrared) of SLC-off ETM+ images, few researches have been done to reconstruct the thermal band, although it has been used widely, such as for urban heat island (UHI) (Chen et al., 2006; Rajasekar and Weng, 2009), water environment (Wloczyk et al., 2006), volcanic activity (Flynn et al., 2001) and geothermal exploration (Yang et al., 2003). The thermal band of SLC-off ETM+ images should be useful for scientific applications, provided that a suitable recovering procedure is implemented.

The similarities between CBERS (China Brazil Earth Resources Satellite) and Landsat 7 ETM+ in view of the band settings and pass over time may provide us an opportunity to recover the SLC-off ETM+ image (Chen et al., 2010). Previous study showed that the imagery integrity of the recovered SLC-off ETM+ image (particularly for the multispectral bands) was fully obtained by using CBERS as auxiliary data, which was superior to one obtained only by using auxiliary data from the same sensor (Chen et al., 2010). Therefore, our main objective is to demonstrate the possibility of using CBERS as auxiliary data to estimate the un-scanned pixels in the thermal band of SLC-off ETM+ image. According to our previous researches, the AWLHM method was selected primarily due to its practicability and reliability, while ignoring its computation speed (Chen et al., 2010). Then a modified sub-procedure was proposed to facilitate the application of the AWLHM method. To show its availability and practicability, the recovering process was applied and evaluated over a simulated SLC-off ETM+ image, by taking Xiamen Island as a case. The accuracy and precision of the recovering procedures were assessed in comparison with the factual data, and the error was discussed.

2. Satellite images

The evaluated data sets used were two Landsat 7 ETM+ images (path/row, 119/043), acquired on January 2, 2002 ($ETM+_{2002}$) and January 21, 2009 ($ETM+_{2009}$, was SLC-off) respectively, and one CBERS-01 image (path /row, 174/041) acquired on November 5, 2002. The spatial resolutions of ETM+ are 15 m for the panchromatic band (band8), 30 m for six visible/near infrared and shortwave infrared bands (band1–5, 7), and 60 m for the thermal band (band6). All bands of CBERS-01 CCD sensor have a spatial resolution of approximately 20 m (namely 19.5 m), however, just three bands (band2, band3, band4) are provided by CRESDA (China Centre for Resource Satellite Data and Application), in view of the images quality. There is band setting similarity between CBERS-01 CCD and Landsat 7 ETM+ in visible/near infrared bands, such as radiometric resolution and bandwidth, as well as their medium spatial resolution (Yang et al., 2004, see Table 1). We estimated the un-scanned pixels in the multispectral bands of SLC-off ETM+ image considering the corresponding bands with similar band setting of CBERS as auxiliary data (Chen et al., 2010).

Xiamen Island, locating in Fujian Province, China, was chosen as our study area. The image of this area is comprised of 585 × 585 pixels in SLC-off ETM+ visible bands, and the total area extent is about 300 km^2.

2.1. Data preprocessing

Multispectral bands of CBERS-01 were re-sampled using the nearest neighbor algorithm with a pixel size of 30 × 30 m, in order to make it compatible to the ETM+ image. It is a vital step that all of the scenes being integrated into a single gap-filled product must be geometrically registered prior to the radiometric adjustment and recovering procedure (USGS and NASA, 2004). Then, the re-sampled CBERS-01 image was co-registered by treating the $ETM+_{2002}$ image as the geometric reference. The RMSE (root mean square error) of rectification was within 0.5 pixels. The thermal bands of ETM+ images were also re-sampled using the nearest neighbor algorithm with a pixel size of 30 × 30 m. All data involved in this study were co-registered in the same coordinate system (UTM/WGS84, N50). According to Darsishi et al. (2008a), a simulated SLC-off thermal image was obtained by implementing the gap mask (indicating the location of the un-scanned pixels, provided along with the original SLC-off data) of the thermal band of image $ETM+_{2009}$ to the thermal band of image $ETM+_{2002}$. Radiometric correction process was not conducted to multispectral bands of CBERS-01, because the data provider (CRESDA) did not give the calibration parameters. Consequently, the raw data in digital number (DN) was used directly in our study. However, considering the fact of temporal changes and differences in the geometry of imaging, absolute radiometric correction is a vital preprocessing step (Darsishi et al., 2008a).

3. Methodology

3.1. The AWLHM method

Soon after SLC-off occurred, a report compiled by the United States Geological Survey (USGS) suggested that,