IMPROVING THE SPATIAL RESOLUTION OF THE ALOS PRISM TRIPLET USING A FUSION TECHNIQUE

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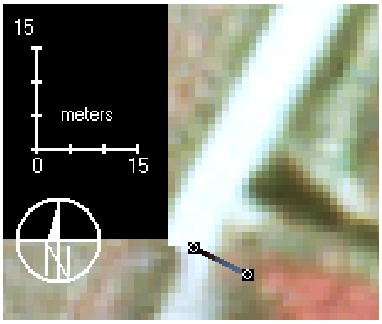
ABSTRACT
We developed a fusion technique to improve the spatial resolution of the triplet of the ALOS PRISM data. The technique used a maximum *a posteriori* estimation framework to obtain a high resolution image from the triplet, and it was the combination of the blur identification and high resolution image reconstruction. In particular, an iterative scheme based on the alternating minimization was developed to estimate the blur and high resolution image progressively, and a hybrid optical flow registration method was then used to estimate the deformation coming from hypsography. Results showed that the fusion technique was effective, and improved the resolution.

INTRODUCTION

There is a great need to have fine spatial resolution data with high fidelity and consistence in geo-referencing and intensity (tone) in the studies of land cover and landuse (LCLU), and their changes. On the basis of a land cover classification system (Anderson et al. 1976), as the LCLU level varies from I to IV, the requirements of spatial resolution changes from a pixel of 30-80 × 30-80 m to a pixel of ≤ 0.5 × ≤ 0.5 m in size (Welch 1982, Jensen et al. 1983). Thus, with the increase of spatial resolution and in an urban area, for example, the detailed information ranging from urban or built-up area (Level I), residential or commercial area (Level II), single-family or multi-unit apartment (Level III), to finally a single house, houseboat, hut, or tent (Level IV) can be obtained.

Traditionally, airphotos are primary sources for the hi-resolution data, and they have been widely and successfully used. One of the most recent and noticeable examples is the GoogleEarth (http://earth.google.com), where multi-layers of airphotos and/or satellite images with different spatial resolutions are stored in a database. One can retrieve the data through a browser (i.e., GoogleEarth). Furthermore, different US governmental agencies and private entities acquire and provide hi-resolution airborne data to users. For example, the USGS offers nation-wide digital orthophoto quarter quadrangles (DOQQs) in B/W, natural color, or false color IR images. The pixel size is 1 × 1 m. The DOQQs are cheap to order or free in some cases. For instance, the 1998 false color IR DOQQs of North Carolina can be downloaded for free at http://www.nconemap.com. Each DOQQ covers an area of 3.75º (lat.) × 3.75º (lon.). For area near 35º latitude, the area is about 6.5 (east-west) × 7.5 km (north-south) or 48.8 km^2. A mosaic of several DOQQs is needed if an area of interest is greater than an area covered by one DOQQ. However, there can be three concerns: the possible mis-geo-referencing of multi-DOQQs, variation of radiometric characteristics of adjacent DOQQs, and low temporal resolution. Fig. 1a shows a mosaic of two 1998 DOQQs. A road is off 8-10 m at the boundary of two DOQQs. Fig. 1b is another example indicating the large variation of radiometric characteristics of adjacent DOQQs. It is difficult to correct the DOQQs radiometrically and it is definitely impossible to apply the same method/algorithm to study the mosaic without the correction. The temporal resolution is low and typically in years for the DOQQs. Therefore, due to the lack of repetitive coverage the use of hi-resolution airborne data (e.g., DOQQs) can be potentially limited in the study of some events (e.g., coastal changes caused by storms) that are time sensitive. However, advances in remote sensing technology and new satellite platforms can overcome the problems and ease or maybe remove the concerns. For example, the successful launch of the Advanced Land Observation Satellite (ALOS) in January 2006 by the Japanese Aerospace Exploration Agency (JAXA), and initiation of the data delivery in December 2006 may now help fill the need for remotely sensed data in time-essential coastal applications.

(a)



(b)

Figure 1. (a) A mosaic of two DOQQs. A road is not connected. (b) a mosaic of six DOQQs, on which radiometric characteristics vary greatly.

One sensor onboard the ALOS is the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) consisting of three identical sensors, one looking forward, one looking nadir, and one looking backward. The wavelength of the sensor is 0.52–0.77 μm. The PRISM operates in one of three modes in data acquisition, collecting the data in triplets (forward, nadir, and backward views) simultaneously, nadir and backward views simultaneously, or nadir view only. The PRISM sensor offers optical data with high radiometric fidelity by its advanced line-scanner imagers, good geo-referencing among individual images due to the high altitude of the satellite, and high temporal resolution because the sensor is onboard an operational satellite. The cost to order a triplet from the Alaska Satellite Facility (http://www.asf.alaska.edu) is currently $125 for a general user. However, the spatial resolution of the PRISM data is 2.5 × 2.5 m, which is coarser than data with 1 × 1 m resolution. In this paper, we present a recent study to improve the spatial resolution of the PRISM triplet using a fusion technique.

ANALYTICAL APPROACH

PRISM Triplet Data

To derive the global digital elevation model (DEM) or digital surface model (DSM) data, scientists at JAXA developed the PRISM sensor (http://www.eorc.jaxa.jp/ALOS/about/prism.htm). The sensor consists of three identical optical sensors, one looking forward, one looking down or nadir, and one looking backward. When three sensors collecting data for the same ground location in tens of seconds apart, the result is a triplet. A triplet covers an area of 35.0 by 35.0 km or 1,225.0 km^2, which is about 25 times larger than the ground coverage of a DOQQ (at the latitude of 35º). Due to the three-looking configuration in geometry, the same ground location is observed at three different viewing points. Thus, the PRISM data can not only theoretically be used to derive the DSMs, but also to create datasets with higher spatial resolution than individual (forward-, nadir-, or backward- looking) images in the triplet. We summarize a maximum *a posteriori* estimation framework or fusion to derive a hi-resolution image from the triplet next.

Fusion

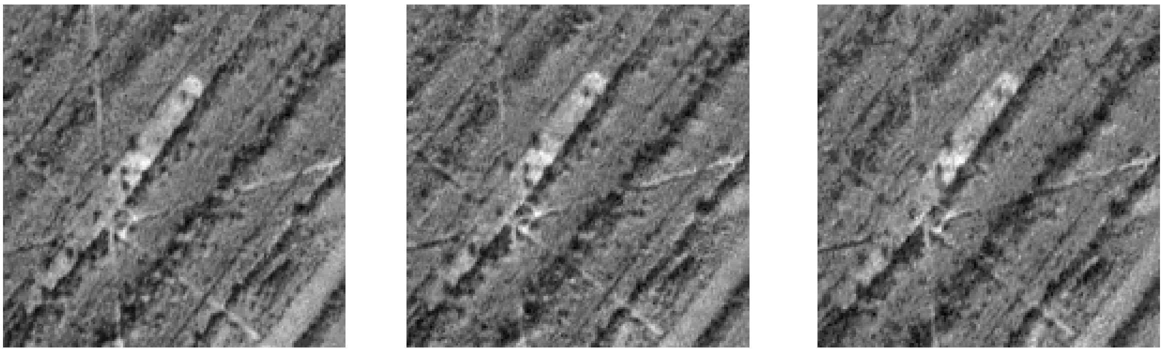
Let us assume that a set of N low resolution images g_i ($i = 1, 2, \ldots, N$ and each with a size $M \times M$) that represent different levels of resolution degradation of a single high resolution image f of size [$L \times L$], where $L > M$. In the case of a triplet, $N = 3$. The resolution degradation is the result of a uniform rational decimating (D_0) performed on the high-resolution image, a linear space-invariant blurring (C_i), and an arbitrary geometric warping (W_i). Also, each low resolution image is contaminated by non-homogeneous additive Gaussian noise n_i. Thus, the relationship among the low and high resolution images can be,

$$g_i = D_0 C_i W_i f + n_i \tag{1}$$

Sroubek et al (2007) manipulated eqn. (1), and provided a solution for a set of N low resolution images using the energy function. We apply their method and solve eqn. (1) from the triplet in two major steps. First, we use a hybrid optical flow registration method to deal with the deformation that is brought by hypsography. Second, in order to reconstruct or derive the high-resolution image, we apply an iterative scheme based on alternating minimization to estimate the blur and high resolution image progressively (Gong et al. 2008).

RESULTS

We have applied the fusion technique to two PRISM triplets, one scene covering a forested area from coastal North Carolina, USA, and the other an urban/suburban area in the city of Wuhan, China. The triplet of the North Carolina coast was acquired on 26 November 2006, and the other triplet on 27 September 2006. Both were ordered directly from the Alaska Satellite Facility (http://www.asf.alaska.edu). The processing level is Level 1B2G, i.e., the data were geometrically and radiometrically corrected. Figure 2 shows three images of the triplet from the forested area. Roads and row patterns of trees are noticeable. The image size is 160 rows by 160 columns. The *SNR* of each image is between 13.7 and 15.3 *dB*. Figure 3 shows the derived image using the fusion technique. The image size is 320 rows by 320 columns, or an increase by a factor of 2. Individual trees after the fusion are easier to be identified as compared to trees before the fusion. The fusion technique has also been used to the urban scene. After the fusion (Fig. 4a), the edges of buildings are much shaper than those before the fusion. The spatial resolution has been improved (Fig. 4a) as compared to the nadir view image (Fig.



(a) A backward-look image. (b) A nadir-looking image. (c) A forward-looking image.

Figure 2. The individual image of the triplet for a forested area in North Carolina coast, USA.

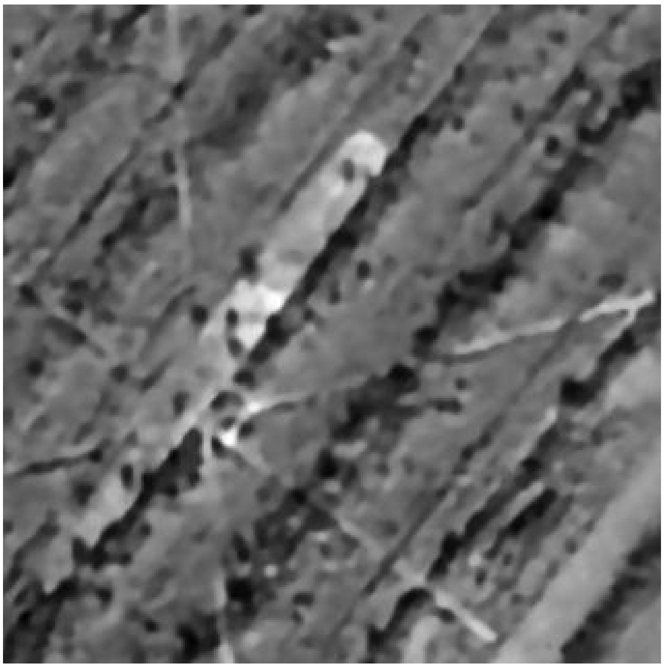
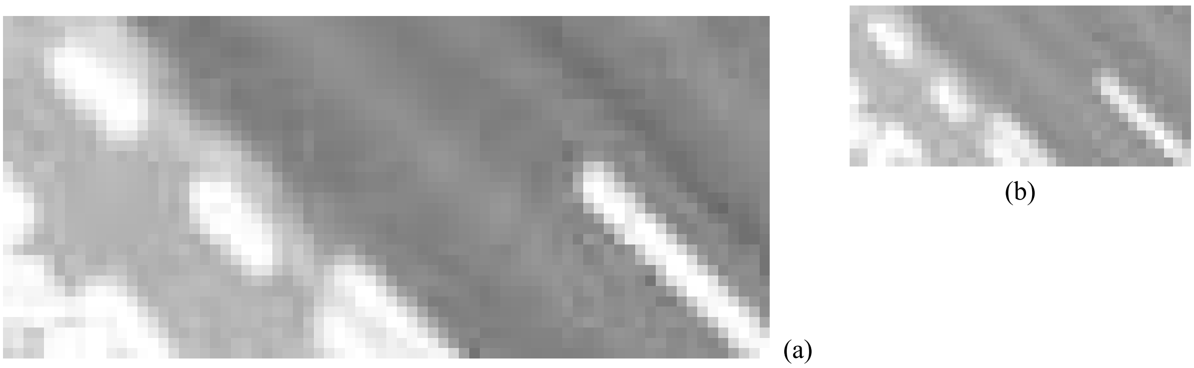


Figure 3. An image after fusion of the triplet. The image size is about 320 x 320, or there is an increase by a factor of 2 in x and y directions, respectively.



(a) (b)

Figure 4. An urban scene of Wuhan, China. (a) After the fusion, and (b) the nadir-view image.

4b). Again, the improvement factor on the spatial resolution is near 2. However, there is blurring in the derived image (fig. 3 or fig. 4a), and we attribute the blurring to the low *SNR* of the triplet. Further investigation of the impact of the *SNR* on the fusion is planned, and de-noising methods will be considered.

CONCLUDING REMARKS

A fusion technique using the PRISM triplet as input has been developed to improve the spatial resolution. The technique is based on the maximum *a posteriori* estimation framework to obtain or reconstruct a high resolution from a triplet. The technique includes the blurring identification where an iterative scheme based on alternating minimization is used to estimate the blur and high resolution progressively. It also includes the high resolution image reconstruction where a hybrid optical flow registration method is employed to estimate the high resolution deformation that is coming from the hypsography. The resolution of a triplet after the fusion can be theoretically improved up to a factor of 3. Results show that the method is effective in performing high resolution image reconstruction using the triplet and data quality of the triplet impacts the fusion data indeed. Future work is needed to further assess the fusion technique. One possible assessment will compare the fusion result versus a high resolution data (preferably with a spatial resolution of 0.5 × 0.5 m or better, and with almost the same season/month of data acquisition). Another one is quantifying the impact of the *SNR* on the improvement factor. Thus, one can answer what is the improvement factor of the spatial resolution at a given *SNR* of the triplet.

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