Improving the spatial resolution of the ALOS PRISM triplet using a fusion technique

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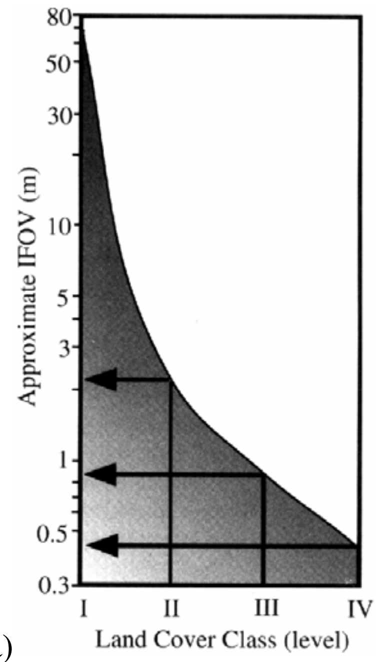
Abstract

We developed a fusion technique to improve the spatial resolution of the triplet of the PRISM data. The technique included a maximum *a posteriori* estimation framework to obtain a high resolution image from the triplets. The algorithm combined the blur identification and high resolution image reconstruction. An iterative scheme based on the alternating minimization was developed to estimate the blur and high resolution image progressively. 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.

1. Introduction

There is a great need to have hi-spatial resolution data with high fidelity in geo-referencing and high consistence in amplitude or intensity (tone) in the studies of landuse and land cover, and their changes. For instance, on the basis of the USGS land cover classification system (Anderson et al. 1976, and Fig. 1), as the level increases from I to IV, the requirements of spatial resolution changes from a pixel of 30-80 m x 30-80 m in size to a pixel of ≤ 0.5 m x ≤ 0.5 m in size (Welch 1982, Jensen et al. 1983). Thus, with the increase of resolution in an urban area, the detailed information ranging from urban or built-up land (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.



(a)

(b) Level I (1) – urban or built-up area;

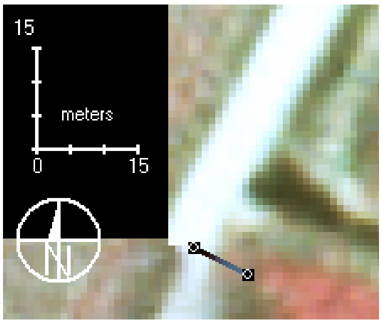
Level II (11) – Residential area;

Level III (111) – Single family residential area; and

Level IV (1111) – Single house, houseboat, hut, or tent.

Fig. 1, (a) Spatial resolution as a function of the mapping requirements for Levels I to IV, and (b) an example of urban classification in four levels.

Traditionally, airphotos are primary sources for the hi-resolution data, and they have been widely used. Many successful examples can be found. Recently, one of the most noticeable ones is the GoogleEarth (http://earth.google.com), where multi-layers of images with different spatial resolutions are incorporated and are retrievable from a database through a browser (i.e., GoogleEarth). Furthermore, US governmental agencies acquire and provide hi-resolution airborne data to users. For example, USGS offers the digital orthophoto quarter quadrangle (DOQQ) false color IR image. The pixel size is 1 m x 1 m. The DOQQs cover the entire continent US and they are cheap to order or free. In North Carolina, the DOQQs of 1998 can be downloaded for free. Each DOQQ covers an area of 3.75º (lat.) x 3.75 º (lon.). For area near 35º latitude, the area is about 6.5 km (lon. or east-west) x 7.5 km (lat. or north-south) or 48.8 km^2. The mosaic of several DOQQs is needed when an area of interest is greater the area covered by a single DOQQ. However, there are three concerns that a user is always facing: the possible mis-geo-referencing of multi-quadrangles, variation of radiometric characteristics of the data, and temporal resolution. Fig. 2a shows a mosaic of two DOQQs, where a road is off about 8-10 m. (You would be off the road if you were driving crossing the boundaries.) Fig. 2b is another example indicating the large variation of radiometric characteristics of adjacent DOQQs. It is difficulty and tedious to correct the DOQQs radiometrically and it is definitely impossible to apply the same procedure/method to study the mosaic without the radiometric correction. The temporal resolution is 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 easy or maybe remove the concerns. For example, the ALOS sensors successfully launched by the JAXA in January of 2006 may now help fill the need for remotely sensed data in time-essential coastal applications. In particular, the PRISM sensor offers optical data with high radiometric fidelity by its advanced CCDs of line-scanner imagers, good geo-referencing among individual images (due to the high altitude of the satellite), and high temporal resolutions. The spatial resolution of the PRISM data is 2.5 m x 2.5, which is coarser than data with 1 m x 1 m resolution. In this paper, we summaries a recent work in which the spatial resolution of the PRISM triplet data have been improved.

(a)


(b)


Fig. 2, (a) A mosaic of two DOQQs. A road is not connected. (b) a mosaic of six DOQQs, on which radiometric characteristics vary greatly.

2. Analytical approaches

2.1. PRISM triplet data

To derive the global digital elevation model (DEM) or digital surface model (DSM) data, scientists at JAXA developed the PRISM sensor (Fig. 3). The sensor consists of three identical optical sensors, one looking forward, one looking down or nadir, and one looking backward. When three sensors simultaneously collecting data, the result is a triplet. A triplet covers an area of 35 km by 35 km or 1,225 km^2, which is about 25 times larger than a DOQQ (at the latitude of 35°). 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-, and 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.

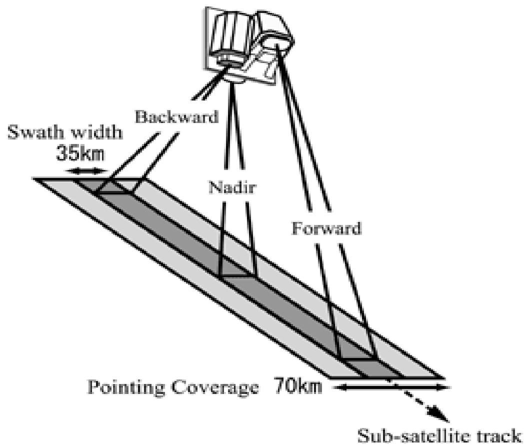


Fig. 3, Geometric configuration of individual sensors of the PRISM (from the JAXA web site).

2.2. Fusion through the blind super-resolution reconstruction

Let us assume that a set of N low resolution images g_i (each with size M x M) that represent different levels of resolution degradation of a single high resolution image f of size [L x L], where $L > M$., and $i = 1, 2, \ldots, N$. In the case of a triplet, $N = 3$. The resolution degradation is the result of an arbitrary geometric warping (W_i), linear space-invariant blurring (C_i), and uniform rational decimating (D_0) performed on the high-resolution image. Finally, 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,

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

Fig. 4 shows an example of the relationship of eqn. (1). The area is near the coast of North Carolina, USA. Sroubek et al (2007) manipulated eqn. (1), and provided a solution for a set of N low resolution images using the energy function. We applied their method to 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).

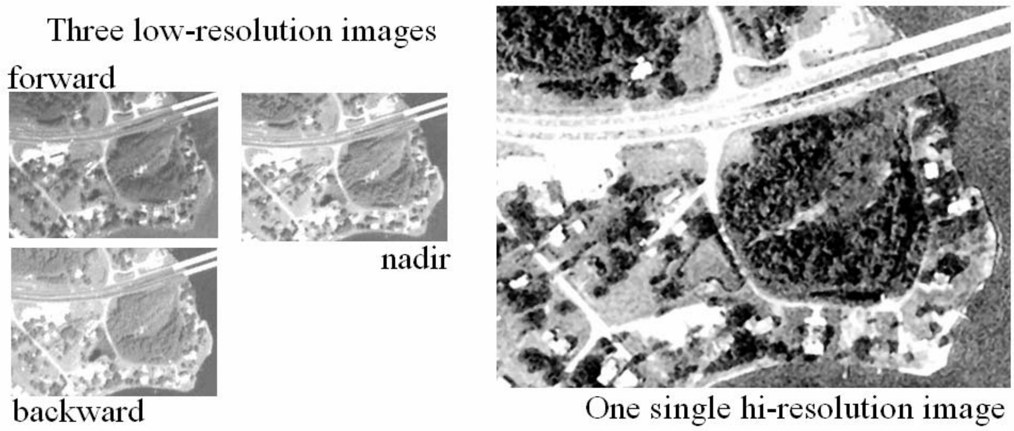


Fig. 4, A triplet of three low-resolution images (forward, nadir, and backward), and one hi-resolution image. (The hi-resolution is an airphoto, and it is not derived from the triplet.)

2.3. Assessment of data quality of a triplet

Data quality of the triplet greatly impacts the fusion technique. The higher the quality, the better the performance/result of the technique. We argue that in the best scenario of the performance, the fusion technique can ideally improve the spatial resolution of the triplet *up to the fact of 3*. Three parameters are used to assess the data quality, the signal-to-noise ratio (*SNR*), entropy, and mean grads. Here, the entropy is,

$$Entropy = -\sum_{i=0}^{255} p_i \log_2 p_i \qquad (2)$$

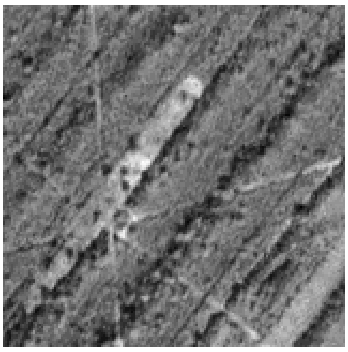
where p_i is the count of histogram of [0, 255]. The mean grads are,

$$MeanGrads = \frac{1}{(L-1)(M-1)} \sum_{i=1}^{(L-1)(M-1)} \sqrt{\frac{\left(\frac{\delta f}{\delta x}\right)^2 + \left(\frac{\delta f}{\delta y}\right)^2}{2}} \qquad (3)$$

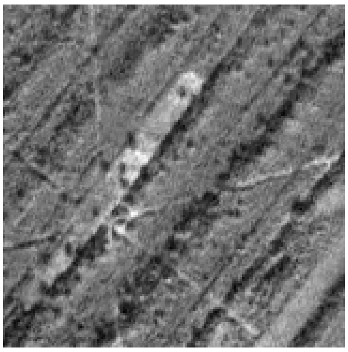
where L is number of rows and M number of columns of the high resolution image f.

3. Results

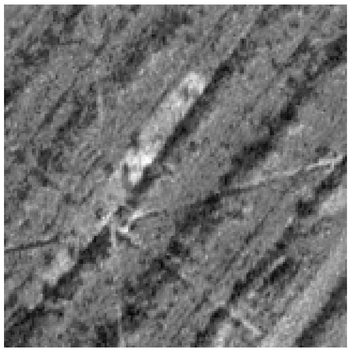
To demonstrate the performance of the fusion technique, we have applied it on two PRISM triplets, one scene covering a forested area from North Carolina coast, USA, and the other an urban/suburban area in the city of Wuhan, China. The triplet of the North Carolina coast was acquired on 26 November 2006, and the triplet for the China scene on 27 September 2006. Both were ordered directly from the ASF. The processing level is Level 1B2G, i.e., the data were geometrically and radiometrically corrected. Figure 5 shows three images of the triplet from the forested area. Roads and row patterns of trees are noticeable. Their size is 160 rows by 160 columns. The *SNR* of each image in the triplet is between 13.7 and 15.3 *dB*, entropy between 4.2 and 4.4, and mean grads 42.7 and 44.8. Figure 6 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 applied to the urban scene. After the fusion (Fig. 7a), the edges of buildings are much shaper than those before the fusion. The spatial resolution has been improved (Fig. 7a) as compared to the nadir view image (Fig. 7b). Again, the improvement factor on the spatial resolution is near 2. However, there is blurring in the derived image (fig. 6 or fig. 7a), 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. De-noising methods will be employed.



(a) A backward-look image



(b) A nadir-looking image



(c) A forward-looking image

Fig. 5, The individual image of the triplet for a forested area in North Carolina coast, USA.

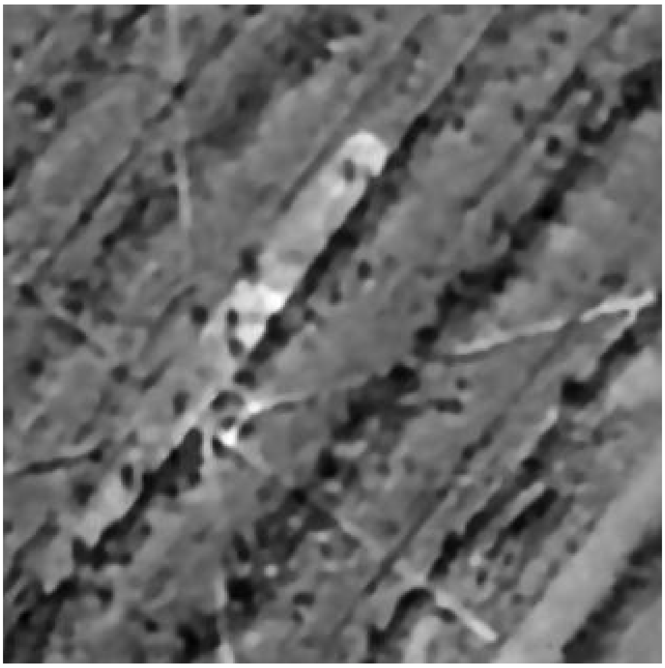
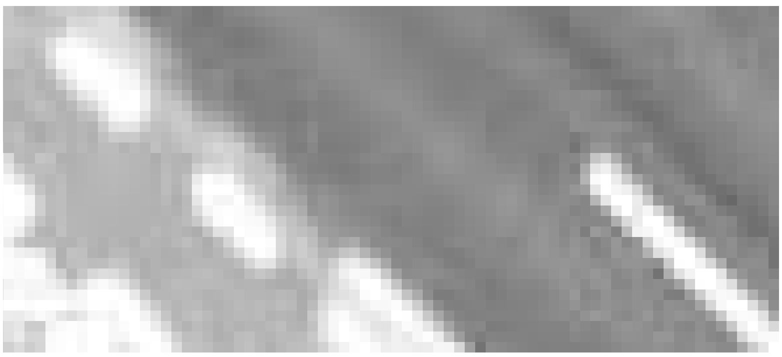
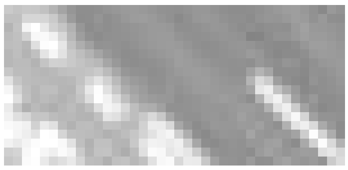


Fig. 6, Fusioned image from the triplet. The image size is about 320 x 320, or there is an increase by a factor of 2 in x and y directions, respectively.



(a)



(b)

Fig. 7, An urban scene of Wuhan, China. (a) After the fusion, and (b) the nadir-view image.

4. 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, and 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 that the data quality of the triplet impacts the fusioned data. Future work is needed to further assess the fusion technique. One possible assessment will compare the fusioned result versus a high resolution data (preferably with a spatial resolution of 0.5 m x 0.5 m or better). 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.

5. Acknowledgment

ALOS PRISM data were provided by the JAXA through a contract to East Carolina University (ALOS PI# 42).

6. References

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