SPATIAL ENHANCEMENT TECHNIQUES FOR MULTICHANNEL SATELLITE IMAGERY

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Abstract

Global and local multi-band spatial enhancement techniques for digital imagery are described. The techniques are based on a least-squares approach, and utilize correlation between a low resolution image of one spectral wavelength and a high resolution reference image of a different wavelength in order to augment the high spatial frequency content of the low resolution image. The limitations of the global approach motivate a local approach based on a sliding window technique. Using the local enhancement approach, the apparent ground resolution for TM thermal imagery and SPOT multispectral imagery is improved from 120 to 30 meters and 20 to 10 meters, respectively.

1. Introduction

The accurate exploitation of digital images depends on the quality of the input imagery. For multispectral imagery, it is important that the individual spectral bands display similar spatial characteristics. The Landsat-D Thematic Mapper collects imagery in seven spectral bands, ranging from visible, through the reflective infrared (IR) to the thermal IR. The ground resolution of the visible and IR images is 30x30 meters whereas for the thermal image it is 120x120 meters. The SPOT Image sensor will collect imagery in four spectral bands, panchromatic, visible and IR. The wideband panchromatic band will exhibit 10x10 meter ground resolution, whereas the visible and IR bands have only 20 meter resolution. Normally, TM thermal data is not used because of its lower resolution, and SPOT multispectral data would be processed at 20 meter resolution.

The most desirable exploitation scheme for each of these data sets is to process them at the highest spatial resolution that the data supports, i.e., at 20 meters for the TM and 10 meters for SPOT. This paper describes two pre-processing techniques that facilitate this type of data exploitation. A primary assumption is that objects not resolvable in the low resolution data may not be resolved in the enhanced data. In particular, the goal is to sharpen the edges of large objects to the effective resolution of the high resolution reference imagery. The importance of these pre-processing techniques is underscored by observations by Swain et. al. that a significant improvement in ground classification accuracy (from 70% to 90%) could be achieved by improving the resolution of the

TM thermal band [1].

The organization of this paper is as follows. First a description of a global technique for incorporating high frequency information from a reference image is given. Next the local approach is described with some implementation considerations for the local least-squares algorithm. Finally, the effectiveness of the techniques on TM thermal and SPOT data is illustrated in the last section.

2. Global Enhancement Approach

A global multi-band enhancement method is described in this section. The overall procedure is based on normalizing the intensities of a high resolution reference image, i_{ref}, to match those of the image of interest, i_{input}, and then incorporating the high spatial frequency content of the normalized image, $\hat{i}_{ref}$, into the image of interest. The normalization is accomplished by linear regression, i.e. computing two constants, b_0 and b_1, so that the following error,

$$||i_{input} - \hat{i}_{ref}|| = ||i_{input} - (b_1 i_{ref} + b_0)|| \quad (1)$$

is minimized over the entire image. If more than one reference image is available, then the optimal linear combination of references is computed to derive the best normalized image. In order to enhance the input image, the normalized reference is high-pass filtered and then added to the input image, i.e.,

$$i_{enhanced} = i_{input} + h_{HP}(\hat{i}_{ref}) \quad (2)$$

where the high frequency cutoff for the filter is chosen to correspond to the spatial bandwidth of the input image.

To illustrate this approach, a TM IR image is enhanced from 120 meters to 30 meters resolution. The image in Fig. 1 is a TM band 5 image that has been blurred and subsampled to simulate a 120 meter resolution image. The spatially enhanced IR image (Fig. 3) is generated using the simulated 120 meter IR image as the input and the visible TM band 2 (Fig. 2) as the reference. The effect of global sharpening is more apparent in some areas in the image than others for the reasons decribed below.

In the global approach, by normalizing the reference first, the sign and amplitude of the high frequency edges are approximately correct for enhancement purposes whenever the reference and input images are highly correlated. The obvious problem with this is that multi-spectral images are, in general, not globally correlated. From the example in Fig. 3, one can observe that the edges of the bright field in the center of the image are not sharpened sufficiently, and that the edges of the river are incorrectly enhanced with reverse contrast edges. A better approach is to derive an improved reference image using a local approach so that the reference is correlated everywhere with the input image.

3. Local Enhancement Approach

The local enhancement technique outlined in this section is described in greater detail in [2]. The local approach is based on the observation that multi-spectral data is highly correlated at a local level (i.e. within a 5x5 pixel window). Exploiting this fact allows locally correlated high resolution reference images to be generated and used for subsequent enhancement.

The implementation for the local approach which implicitly includes reference generation and enhancement is depicted in Fig. 4. The specific implementation was for TM thermal sharpening, but is easily generalized to cover other applications as well. In order to reduce computation, spatial averaging and subsampling is performed prior to reference coefficient generation. The local approach to reference generation is similar to the global approach in that coefficients are computed to minimize an error term as in Eq. (1). In this case, however, the coefficients are spatially dependent and the error minimization is done locally over a small window and for every location of the window. The details of this local least-squares computation are described in [2,3]. This initial procedure produces two images of coefficients $b_0[n,m]$ and $b_1[n,m]$ which are interpolated and then multiplied by the input reference images to produce the locally normalized reference image.

The final enhancement step can either be done by either of two methods. The first method involves straightforward implementation of Eq. (2). The second method is based on feeding the residual error (refer to Fig. 4) forward, interpolating it and then adding it to the final normalized reference. In this case, the enhanced image is the sum of the reference and the interpolated error term. Not only does it exhibit the spatial enhancement from the correlated edges of the reference image, but it is also consistent with the input image by design.

4. TM and SPOT Examples

The local enhancement is now applied to two multi-spectral data sets, TM and SPOT imagery. For the TM example, image bands 1,3,4,5,7 are used as input references to create a spatially enhanced TM thermal band 6 image. The original 120 meter resolution thermal image is shown in Fig. 5. One of the 30 meter resolution reference images (band 2) is shown in Fig. 6. The enhanced thermal image, which displays an effective 30 meter resolution, is presented in Fig. 7. For the SPOT example, the panchromatic band is used as a single reference image to sharpen each of the three multi-spectral bands. The original 20 meter IR band 3 image, the 10 meter panchromatic image, and the enhanced 10 meter IR image are shown in Figs. 8-10.

From the enhanced TM and SPOT imagery, one observes that the local approach produces uniformly sharper images. It is also important to note that no local sharpening is performed when edges exist in the reference images but not in the low resolution input image, and vice versa. A variety of scene types, ranging from rural to urban, have been processed and their enhancements have been consistently good. Validation of the local enhancement technique on simulated imagery is discussed in [3].

5. Summary

A global and local spatial enhancement technique for multichannel satellite imagery was described. Our goal was to spatially sharpen one or more image channels that exhibit poorer resolution than some other channels that can be used as references. The local technique restored the TM thermal band to an effective 30 meter resolution and the 20 meter SPOT visible and IR bands to 10 meters. Our implementation is nonrecursive and is currently being implemented on fast parallel hardware.

Figure 1. Simulated TM IR image at 120 meter resolution.

Figure 2. Reference TM visible image at 30 m. resolution.

Figure 3. Enhanced TM IR image at 30 meter resolution.

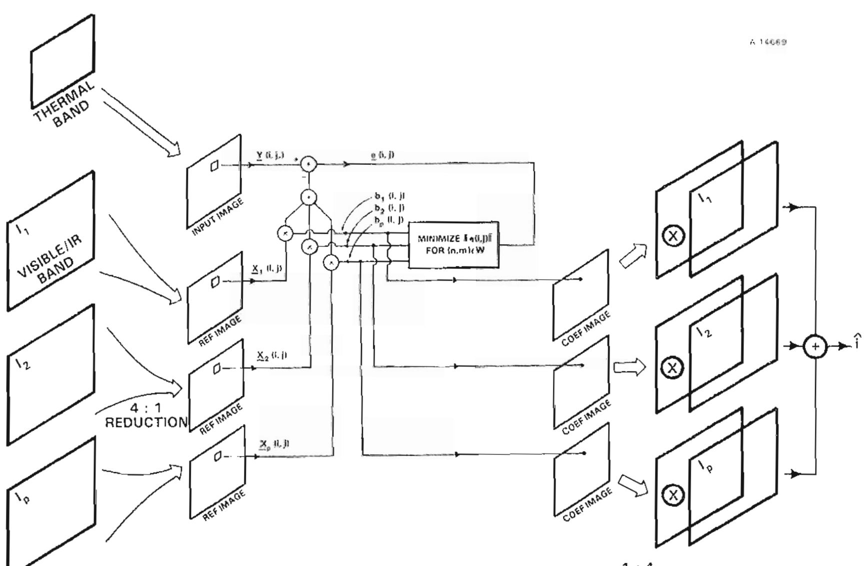

Figure 4. Flow diagram for TM thermal band enhancement implementation.

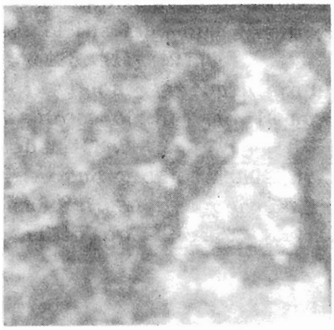

Figure 5. Original TM thermal image at 120 m. resolution.

Figure 6. Reference TM visible image at 30 m. resolution.

Figure 7. Enhanced TM thermal image at 30 m. resolution.

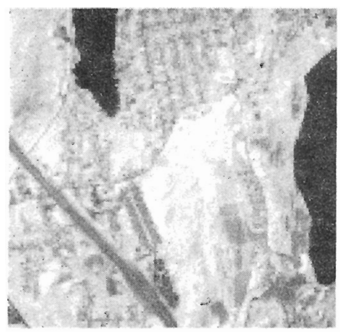

Figure 8. Original SPOT IR image at 20 m. resolution.

Figure 9. Reference SPOT panchromatic image at 10 m. res.

Figure 10. Enhanced SPOT IR image at 10 m. resolution.

References

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[2] Tom, V.T., Carlotto, M.J. and Scholten, D.K., "Spatial resolution improvement of TM thermal band data," Proc. SPIE Applications of Digital Image Processing VII, Vol. 504, 1984, pp. 384-390.

[3] Tom, V.T. and Carlotto, M.J., "Adaptive LS technique for multi-band image enhancment", Proc. International Conference, Acoustics Speech and Signal Processing, Vol. 2, pp. 704-707, 1985.