Oblique Striping Removal in EO-1 Hyperspectral Remote Sensing Imagery

Zohra Hamadache Youcef Smara

(USTHB) Faculty of Electronics and Computer Science Algiers, Algeria
Laboratory of Image Processing and radiation
e-mail: zohra.hamadache@yahoo.fr , yousmara@yahoo.com

***Abstract*— Contrary to the airborne Hyperspectral data, the Signal-to-Noise Ratio (SNR) of the spaceborne Hyperspectral data of the Hyperion instrument falls from 500 to 50, and Hyperion data are affected by the Striping effect related to a small relative errors calibration of each detector caused by the pushbroom technology, which need to be corrected in order to get a better image analysis and interpretation of Hyperion data. Oblique sharp and repetitive Stripes in remote sensing imagery can distractingly and obstructively affect the interpretation and application of remote sensing data. In this communication, a methodology for removing oblique Stripes is proposed. The technique has been tested taking Hyperion imagery as an example and evaluated. The results show that the proposed method can reduce oblique Stripes effectively and keep most image information. This preprocessing is followed by Spectral features analysis and a supervised Classification to see whether the data were preserved or disturbed after Striping noise reduction. To ensure the reliability of our Classification, we used a data reduction method, which is the Principal Components Analysis (PCA). In this study, Hyperion geotiff data of Oran town (Algeria) site provided by the EO-1 Mission, NASA/USGS was used. This image was acquired in march 03, 2003, it has width 256 cross-track samples, 242 spectral channels and obliquely striped.**

Keywords-Hyperion; oblique striping effect; Hyperspectral; Classification; Spectral analysis; PCA; Wavelet transform.

I. INTRODUCTION

The effect known as "Striping" was visually obvious in all Hyperion data. If one detector of an array (in either the VNIR or SWIR arrays) has a slightly modified or unbalanced response from that of its neighbours or from its normal condition, the result is a vertical "stripe" in the corresponding band of the image data. If the difference of this response is persistent, the effect can be reduced or eliminated by "fine tuning" the calibrations which are normally different for each detector array [1]. The stripes are present in most channels to some degree but are often pronounced in the SWIR and in channels with low SNR [2]. Data of extreme bands (bands which contain little or no valid data) are identified as "bad" pixels and each column in a single band corresponds to a single detector in one of the arrays. Correlated blocks of stripes seem more prevalent in the SWIR than the VNIR [3]. Since the data are generated from separate detector arrays, which utilise different detector materials, the striping effects had different characteristics in the VNIR and SWIR arrays [1]. To reduce the striping effect, several methods exist in the literature such those based on statistics-based algorithm and those based on spectral filtering. This paper focuses on the oblique destriping using Discrete Wavelet Transform (DWT) and the algorithm has been provided as an IDL script. The goal of this study is the correction of the striping effect in order to be able to exploit the hyperspectral data in an optimal way, because oblique stripes will lead to faulty interpretation results of the data. Therefore, a striping noise reduction algorithm that provides optimal results in both the reduction of the oblique stripes in the image and the preservation of the original information should be applied. Thus, it will be a question of developing the adopted approach as an important part of the Hyperion processing.

The paper is organized as follows. In Section 2, we describe the process of oblique destriping algorithm using Discrete Wavelet Transform (DWT). In Section 3 we present our experimental results of applying this algorithm to the Hyperion data (georeferenced) of Oran (Algeria) site in order to correct oblique Stripes. In Section 4, we discuss the results obtained by the X profiles plotting to see the amount of alteration to the initial signal of the Hyperion sensor. An overview of the evaluation results by a supervised Classification can be seen in Section 5. Finally in Section 6 the work will be concluded.

II. OBLIQUE STRIPING REMOVAL USING DWT

The developed oblique striping removal using DWT [4] has been developed to remove oblique stripes in Hyperion data on the assumption that the detector-to-detector variation changes with time and that ground targets in the image area are inhomogeneous. The algorithm is based on locating the frequency components produced by oblique stripes and eliminating them by a specifically designed filter.

The method has the advantage of being usable on georeferenced images. To remove the stripes in a frequency domain with minimum negative effect on the Spectral quality of remote sensing imagery, the frequency components caused by oblique stripes must be located. Stripes are distributed obliquely on the image, so they can be seen as high frequency components in the along-track or cross-track direction.

These high-frequency components, however, mix with the high-frequency components produced by the non-stripe image information, so they cannot be easily found. The stripe-induced frequency components exist in all columns or rows of an image, which suggests that the frequency components induced by oblique stripes may be located by summing the frequency power spectra of each column or row and then averaging the sum **[4]**.

A. Algorithm steps of the oblique Striping removal using DWT

The destriping steps of the developed oblique striping removal using DWT are described as follows (Figure 1):

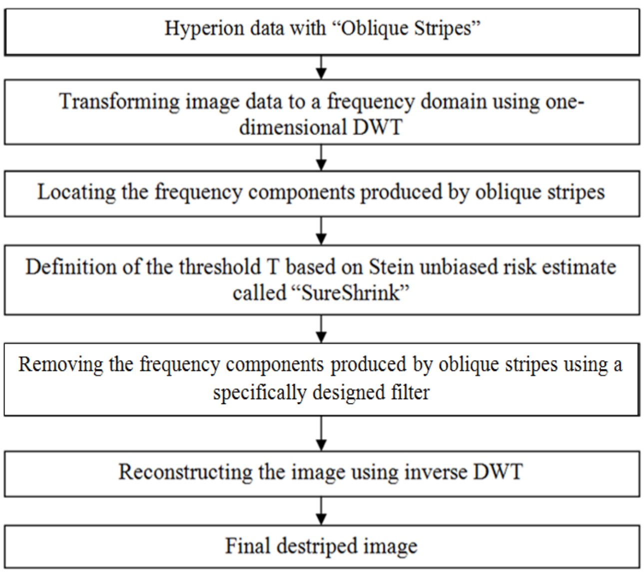


Figure 1. Algorithm steps of the developed oblique Striping removal using DWT

The routine of the oblique striping removal using DWT consists of five major steps:

1) Step 1: Transforming image data to a frequency domain using one-dimensional DWT

The approach adopts one-dimensional DWT to transform an original image from a space domain into a frequency domain column by column or row by row. There are many different Wavelet transforms based on wavelet functions. Here, the well-known Daubechies (db1) wavelet function is employed to decompose each column of the image to four frequency components: one low-frequency component and three high frequency components. The layer number of wavelet transform is two; it can be adjusted to control the destriping effect. Assuming the image has the size of $M*N$, the result is obtained after this step:

$$(P_{Li}, P_{Hi1}, P_{Hi2}, P_{Hi3}) = DWT(f_i) \qquad (1)$$

where f_i is the column or row of original image, P is the power spectrum of each frequency component and i is the number of the column or row. After transformation, each column or row of original image is decomposed to one low-frequency component P_{Li} and three high frequency components, P_{Hi1}, P_{Hi2} and P_{Hi3}, where L represents low-frequency component and H, high-frequency component **[4]**.

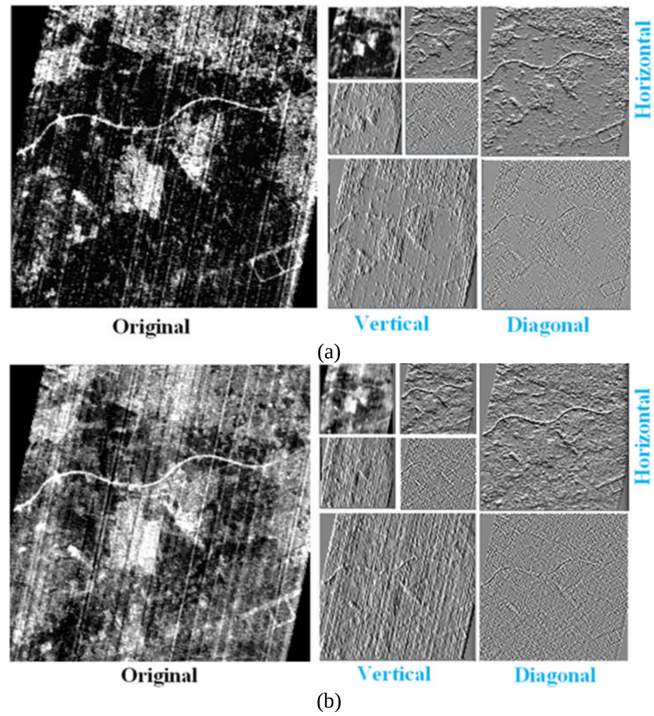


Figure 2. The wavelet decomposition up to the level 2 results on the Oran (Algeria) site of the Hyperion images

Figure 2 demonstrates two-level decimated wavelet decomposition of the Hyperion sensor, where (a) represents Band-62 (976.70 nm) and (b) represents Band-111 (1255.53 nm) images of Oran (Algeria) site using the Daubechies one denoted by db1 in the rest of the text.

Because of mixing of the frequency components caused by stripes, all information related to the oblique stripes impairing the original Oran (Algeria) images cannot be detached exclusively to a single component (i.e., to the horizontal or to the vertical or to the diagonal) details bands of the decomposed image.

2) Step 2: Locating the frequency components produced by oblique Stripes

Single P_{Hin} cannot locate the frequency components caused by oblique stripes in the power spectrum because of mixing of the frequency components caused by stripes and by non-stripe information. The sum of P_{Hin} is averaged to obtain a mean one dimensional power spectrum:

$$Mean\ P_{Hij} = \frac{1}{N}\sum_{i=0}^{N-1} P_{Hij} \qquad (2)$$

where i is the number of the column or row of the image and j is the high-frequency component, $j=1,2,3$. As expected, there are many impulses in $Mean\ P_{Hij}$.

These impulses are not all produced by the oblique stripes. Each impulse is in the frequency range $[a_i, b_i]$ and has a peak value P_i corresponding to frequency value F_i . Each frequency component F_{stripe} caused by oblique stripes can be determined by using threshold T **[4]**:

$$F_{stripe} = F_i,\ P_i \geq T \qquad (3)$$

3) Step 3: Definition of the threshold T based on Stein Unbiased Risk Estimate (SURE)

In this work, the threshold T was defined based on Stein unbiased risk estimate called "SURE". Its expression is described as follow **[5]**:

$$SURE(\hat{T},Y) = N + \sum_{i,j=1}^{N}\left[min(|Y|,\hat{T}\right]^2 - 2[1:N] \qquad (4)$$

$$T = arg\,min(SURE(\hat{T},Y)) \qquad (5)$$

where N is number of Wavelet coefficients, Y is the wavelet coefficients and T is the T estimate.

4) Step 4: Removing the frequency components produced by oblique Stripes using a specifically designed filter

After locating the frequency values which may cause stripes, the filter function can be used to remove these frequency values in each frequency range; other frequency values remain the same, which retains most information of the processed image.

$$DP_{Hij} = P_{Hij} * H(f) \qquad a_i < f < b_i \qquad (6)$$

where $H(f)$ is the specific filter used for removing the frequency components and means convolution. In order to remove the frequency components caused by oblique stripes, we used a specifically designed filter **[4]** which can remove certain frequency component described as:

$$H(f) = 1 - exp\left(-\frac{(f - f_{stripe})^2}{\sigma^2}\right) \qquad (7)$$

where parameter σ is used to control the degree of striping removal.

5) Step 5: Reconstructing the image using inverse DWT

$$Df_i = IDWT\ (P_{Li}, DP_{Hi1}, DP_{Hi2}, DP_{Hi3}) \qquad (8)$$

where Df_i is the column or row of the image after destriping **[4]**.

B. Parameter selection

After several tests, the better results for "oblique striping removal using DWT" in terms of retaining most of the image information and striping noise reduction were obtained by using the following input parameters:

- ✓ Standard deviation : $\sigma = 1$
- ✓ Wavelet type: Daubechies one *(db1)*
- ✓ Decomposition level: Level one *(L = 1)*

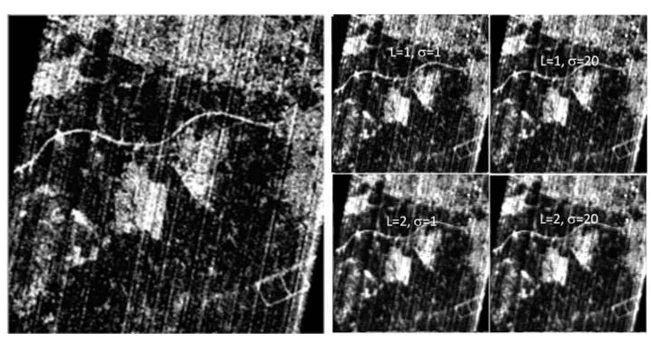
The oblique striping removal using DWT depends on the location of frequency components produced by oblique stripes and is a little time-expensive.

III. Visual Assessment Of Oblique Destriping

In this section, we are going to test and evaluate the results of the developed oblique destriping algorithm in order to correct oblique stripes in Hyperion data without disturbing the information and to get a better image analysis and Classification.

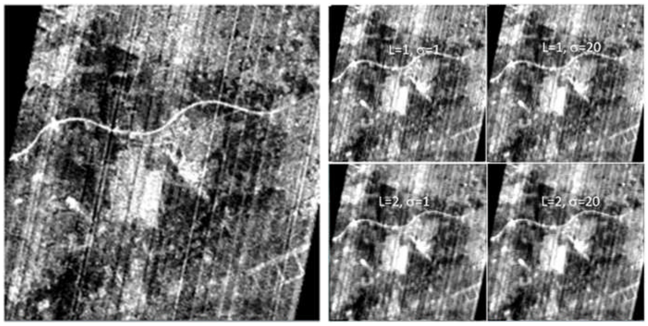
For oblique striping noise, the Hyperion data (georeferenced) of Oran (Algeria) site was used.

After destriping process using the oblique destriping method on the Oran (Algeria) images, the obtained results of the Hyperion Band 62 (976.70 nm) image and the obtained results of the Hyperion Band 111 (1255.53 nm) image are displayed in (Figure 3), where (a) and (a_1) represent the original image of band 62 and band 111 respectively, (b) and (b_1) represent the destriped images of band 62 and 111 respectively by the oblique striping removal using DWT by using different values of parameter σ=1, 20, as well as different highest decomposition levels L=1, 2.



(a) (b)

Band 62 (976.70 nm)

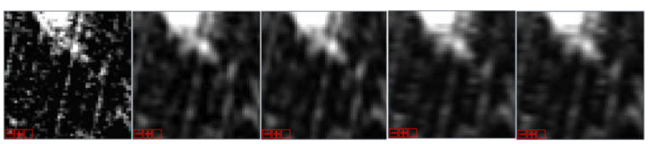


(a_1) (b_1)

Band 111 (1255.53 nm)

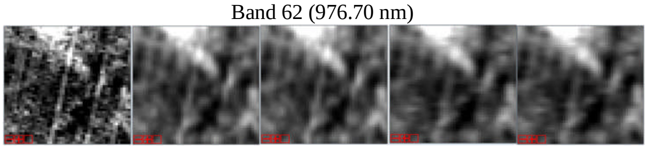
Figure 3. Destriping results on the ORAN (Algeria) site of the Hyperion images.

The results which seem to be good in terms of both striping noise reduction and retaining the information, were collected with the calibrated data using Level 1 and σ=1 as it is demonstrated in the zoomed areas illustrated in (Figure 4), where (a) and (a_1) represent the original image of band 62 and band 111 respectively, (b) and (b_1) represent the oblique destriped images of band 62 and band 111 respectively by using L=1, σ=1, (c) and (c_1) represent the oblique destriped images of band 62 and band 111 respectively by using L=1, σ=20, (d) and (d_1) represent the oblique destriped images of band 62 and band 111 respectively by using L=2, σ=1, (e) and (e_1) represent the oblique destriped images of band 62 and band 111 respectively by using L=2, σ=20.



(a) (b) (c) (d) (e)

Band 62 (976.70 nm)



(a_1) (b_1) (c_1) (d_1) (e_1)

Band 111 (1255.53 nm)

Figure 4. The zoomed areas of the destriping results on the ORAN (Algeria) site of the Hyperion images for the pixel position: (159,164).

By carrying out a comparative study of the various results obtained by both level 1 and 2 as well as σ =1 and σ =20, we noticed that:

Oblique striping removal using DWT (Figure 3) shows an effective reduction of oblique striping noise in the striped bands and a smoothing effect on the output data.

From the zoomed areas (Figure 4), we noticed that:

when *L=1* :

- ✓ for σ =1: the information is better preserved because it becomes more clear.
- ✓ for σ =20: the image becomes slightly blurry

when *L=2*:

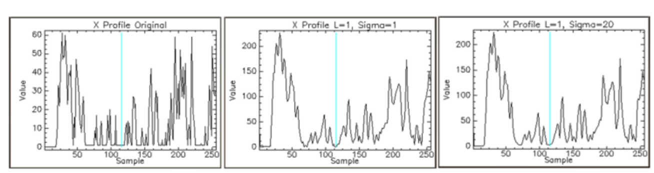
- ✓ for σ=1: the information is better preserved than level 1
- ✓ for σ=20 : the grater the decomposition level is, the image does not change at all, so parameter σ becomes inactive.

As a result, the greater the decomposition level is, the greater the information is preserved and the oblique striping effect is reduced on the same way in both levels. On the other side, the greater parameter σ is in level 1, the more the data become more blurry, but in level 2, parameter σ becomes inactive. In terms of both retaining most of the spectral information and good destriping results, Level 1 and σ=1 are preferred. In term of preserving the information only, Level 2 is preferred and in this case parameter σ has no effect.

IV. Assessment By X Profiles Plotting

To see the amount of alteration to the initial signal of the Hyperion sensor, the plots of x profiles have been calculated from the original data as well as from each destriping result. These profiles can be used to evaluate the ability of the developed oblique destriping algorithms to eliminate or reduce striping patterns without altering the spectral information.

For the oblique destriping, we vary the display of X Profile of Oran (Algeria) site of the Hyperion Band 62 (976.70 nm) along line-59 of the oblique destriping method using DWT. The X Profiles of the oblique striping removal using DWT are displayed in (Figure 5), where (a) represents the original data, (b) represents the oblique destriping by using L=1, σ=1, (c) represents the oblique destriping by using L=1, σ=20.



(a) (b) (c)

Figure 5. The X-Profiles plots along line-59 of the oblique destriping method of Oran (Algeria) site of the Hyperion Band 62 (976.70 nm).

We can notice that for L=1, there is less filtering and it is an advantage for the conservation of information but it is a drawback for the striping reduction. The destriping process indicated a smoothed calibrated result and this blurriness is more significant for σ =20 than for σ =1.

V. SUPERVISED CLASSIFICATION

To classify the typical ground objects on Hyperion datasets of Oran (Algeria) site with oblique stripes, there is a reliable image reference to compare to the results of Classification since most of original data are completely free from stripes, this allowed us to consider the original images as reference data because we can see more clearly the typical ground objects.

Then, we made a visual comparison between the classified image before and after processing and the colored composition of original data to see whether the data were preserved or disturbed after destriping process.

To evaluate the performance of the oblique destriping algorithm using DWT by a supervised Classification, we used the PCA for data reduction, then we constructed the training base by choosing 6 classes, and we applied a supervised Classification by the Maximum Likelihood tool of ENVI software.

We extracted a training base for the Hyperion datasets of Oran (Algeria) site. In fact, we selected six classes of typical ground objects (Table 1). These classes are: Urban, Bare Soil with strong reflectance, Sparse Vegetation, Vegetation, Bare Soil and No Data.

TABLE 1. THE TRAINING BASE DATA OF THE HYPERION DATASETS OF ORAN (ALGERIA) SITE

Selected Classes		Typical ground objects	Number of samples of the training base
Region 1: Red		Bare Soil With Strong Reflectance	204 points
Region 2: Green		Vegetation	196 points
Region 3: Blue		Urban	192 points
Region 4: Yellow		Sparse Vegetation	192 points
Region 5: Cyan		Bare Soil	216 points
Region 6: Magenta		No Data	214 points

Figure 6 below shows the combinations made on the original data, on the destriped data by the oblique destriping by DWT using L=1, σ=1 and L=1, σ=20, as well as the colored composition of the original data using 3 exploitable data (3 components) and 7 exploitable (7 components) after data reduction by the PCA of ENVI denoted by PCA 3 and PCA 7 respectively in the rest of the text, where (a) and (a_1) represent the original images using respectively PCA3 and PCA7, (b) and (b_1) represent the oblique destriped images by using L=1, σ=1 using respectively PCA3 and PCA7, (c) and (c_1) represent the oblique destriped images by using L=1, σ=20 using respectively PCA3 and PCA7, (d) and (d_1) represent the colored composition of the original data.

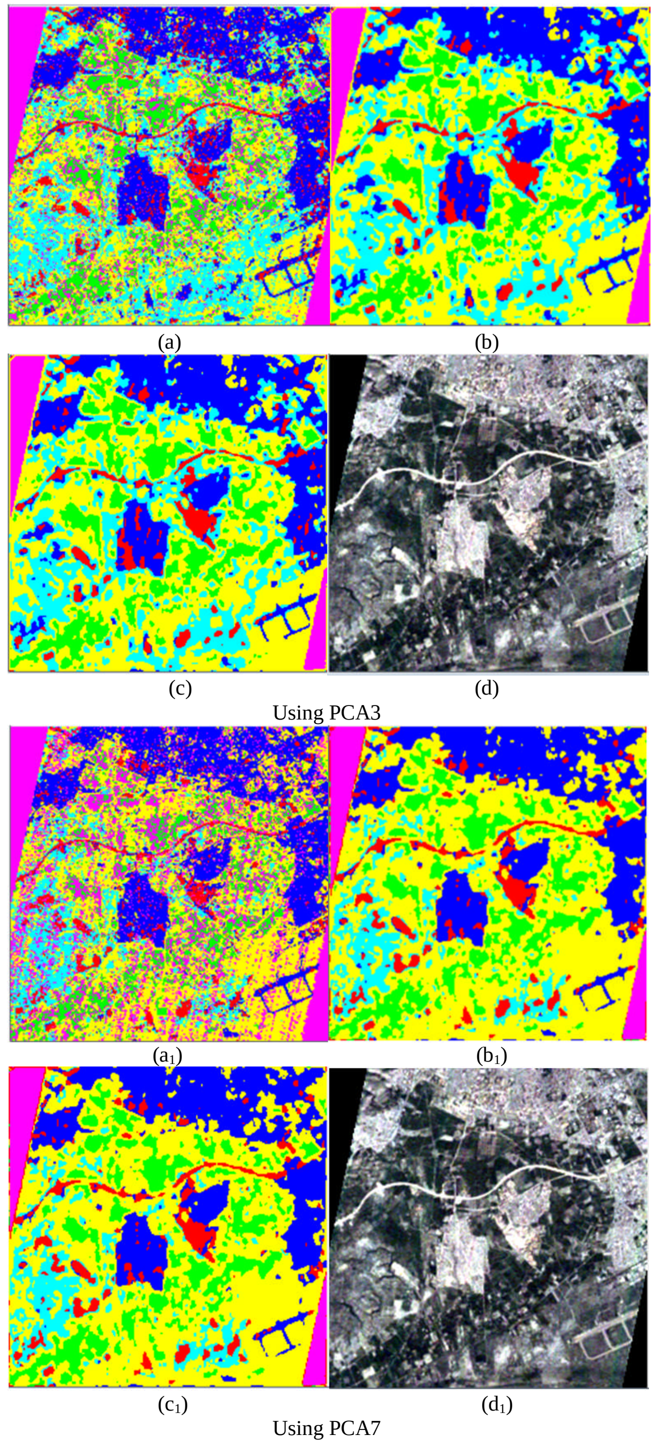


Figure 6. Supervised Classification results of the Hyperion datasets of Oran (Algeria) after data reduction by the PCA.

We selected two different regions in band 62 (976.70 nm): R1 and R2 (Figure 7).

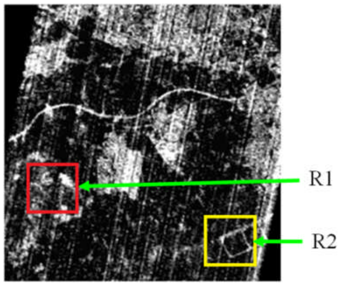


Figure 7. The two selected regions in band 62 (976.70 nm)

The main reason for selecting these two different pixels positions is that the advantage of the developed approach can be demonstrated more clearly. In contrast, the results which seem to be good are displayed in the zoomed areas illustrated below (Figure 8), where (a) and (a1) represent the original images using respectively PCA3 and PCA7, (b) and (b1) represent the oblique destriped images by using L=1, σ=1 using respectively PCA3 and PCA7, (c) and (c1) represent the oblique destriped images by using L=1, σ=20, (d) and (d1) represent the colored composition of the original images.

Region R1:

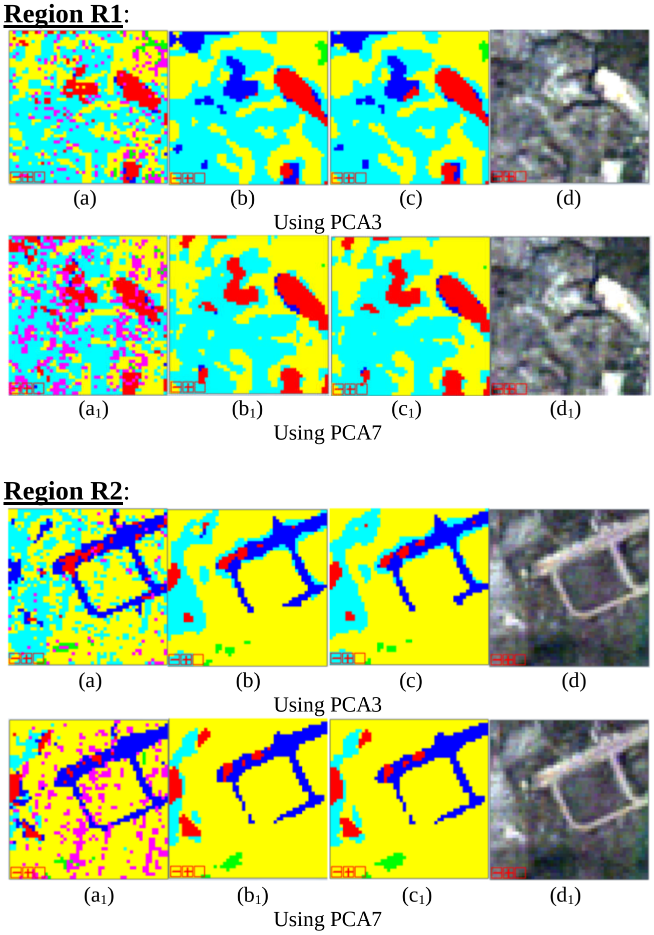


Figure 8. The zoomed areas of the two selected R1 and R2 regions of the supervised Classification results of the position of pixel.

We can notice that:

- For the area R1, the better results were obtained using PCA7 and for the area R2, the better results were obtained using PCA3
- The oblique destriping using DWT indicated bad classified ground objects compared to the colored composition although the zoomed areas displayed that the good results were collected using PCA7 and σ=1 since the classification was more significant, so we noticed an improvement in term of preserving the typical ground objects compared to PCA3.

VI. Conclusion

A destriping approach has been proposed for removing oblique stripes in HYPERION imagery. The destriping results and evaluation showed the method can reduce oblique stripes effectively and keep most of the image information.

However, this technique unavoidably, has more or less effect of smoothing, and DWT is a little time-expensive. The destriping effect of this method depends on the selection of DWT function and location of frequency components produced by stripes.

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