EVALUATION OF IHS, PCA AND WAVELET TRANSFORM FUSION TECHNIQUES FOR THE IDENTIFICATION OF LANDSLIDE SCARS USING SATELLITE DATA

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Abstract. This paper presents an evaluation of IHS, PCA and Wavelet Transform (WT) fusion techniques for the identification of landslide scars using satellite data. The analysis was done using HRV bands (XS1 and XS2) and TM bands (3, 4, 5). A HRV PAN band was simulated by a spectral linear combination between bands XS1 and XS2. The evaluation process consists of visual interpretation, statistical analysis and automatic classification (MAXVER). WT fusion method presents the best result of all evaluation techniques, for the identification of erosion scars. Moreover, this method maintains the high spectral correlation with respect to the original multispectral images. The best statistical results were obtained with the WT method. This method shows correlation values above 91% for the 3 and 5 bands.

Keywords: remote sensing, image fusion techniques, landslides.

1. Introduction

Santa Catarina State, Brazil, due to its peculiar natural conditions and to the intense urban occupation, has suffered catastrophic events like landslides, which caused a great social-economic damage (Herrmann, 2001). In order to reduce this problem, a governmental agency made a field survey at the affected areas, modeled the phenomenon and elaborated maps of the risk area (Guzzetti et al., 1999). According to Carrara et al. (1995), the spatial distribution of past (relict) and recent landslides is the key for predicting slope movements in advance. Hence, the first step is the identification and mapping of all landslide phenomena occurring in the area under study.

Remote Sensing is a fundamental tool for the detection, classification and monitoring of landslide actions. Such technology allows one to obtain historical series, faster collection of data and information at a relatively lower cost (Mantovani et al., 1996; Schowengerdt, 1997). Furthermore, there are several image processing techniques that permit the improvement of image visual quality, making up the poor spatial resolutions of the multi-spectral sensors. Theses techniques are called image merging or image fusion (Carper et al., 1990; Chavez et al., 1991; Garguet-Duport et al., 1996; Yocky, 1996).

Ideally, image fusion techniques should allow combination of the high spatial resolution of an image with the high spectral resolution of another, keeping the basic radiometric information of the latter (Pohl and Genderen, 1998). Furthermore, data fusion provides several advantages such as: preservation of computer storage space, enhancement of aesthetic and cosmetic qualities, analytical improvements and low costs for data obtaining (Carter, 1998). Intensity-Hue-Saturation (IHS), Principal Component Analysis (PCA) and Wavelet Transform (WT) are among the most used image fusion techniques (Carper et al., 1990; Chavez et al., 1991; Grasso, 1993; Garguet-Duport et al., 1996; Yocky, 1996; Garguet-

Duport, 1997; Schowengerdt, 1997; Troya, 1999; Ventura et al., 2002; Li et al., 2002). In this context, the objective of this work is to evaluate IHS, PCA and WT fusion techniques for the identification of landslide scars using orbital optical images of TM and HRV sensors.

2. Study Area

The area under study is located in the Timbé do Sul county in the southern Santa Catarina State, Brazil (**Figure 1**). This size of this area is of about 104,86 Km^2 and it is low population density due to the steep terrain, deep slopes and dense forest. The study area was selected because of the catastrophic event occurred in 23 and 24 December 1995, which caused generalized landslides (debris flow), affecting the hillslope from the Serra Geral in the south region of Santa Catarina (**Figure 2**). The resulting slurry of rock and mud may pick up trees, houses, properties, blocked bridges and tributaries causing extreme flooding along its path. Furthermore, this event killed 29 persons (Pellerin et al., 1997; Valdati, 2000).

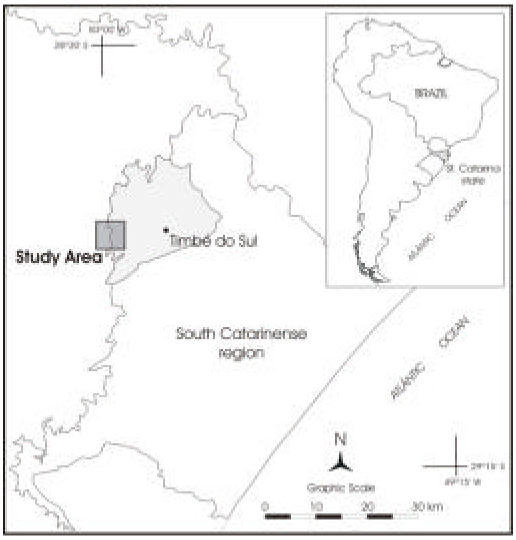

Figure 1 – Location of the area under study.

Figure 2 – Generalized landslides in the hillslopes of Serra Geral.

3. Material and Methods

For this work, were used Landsat 5 TM (30 m resolution) and SPOT 4 HRV (20 m resolution) images, acquired in Nov. 12th '96 and April 6th '96 respectively, close to the time of a landslide event. The images were registered and an the area under study was chosen.

The bands TM 3, TM 5 and TM 7 are more appropriate for observing the landslide features and band TM 4 provides a better contrast between the areas with and without vegetation cover (Sestini, 2000). Taking this into account, we chose the composition 4(R)5(G)3(B) for the scar identification (**Figure 3**). All the image processing phases were performed using the system SPRING 3.51, which was developed by the Division of Image Processing from INPE (Câmara et al., 1996).

A. Pan Simulation

According to Mascarenhas et al. (1991), HRV PAN band was simulated by spectral linear combination between SPOT bands XS1 (0,50 – 0,59 μm) and band XS2 (0,61 – 0,68 μm), applying the following transformation:

$$PAN = \alpha 1 \times XS1 + \alpha 2 \times XS2 \,,$$

where, $\alpha 1$ (0,4937) and $\alpha 2$ (0,5046) are linear constrained estimators; *XS1* and *XS2* are gray levels in multispectral bands XS1 and XS2; and *PAN* is the resulting image with 20 m of spatial resolution. This procedure was adopted because a 10 m PAN image was not available at a date close to the landslide occurrence.

B. Fusion Methods: HIS, PCA and WT

Firstly, the images were radiometrically corrected in order to achieve conformity, i.e., mean and variance equalization (Garguet-Duport et al., 1996). Then, were used the selected bands for IHS fusion. This process consisted in a transformation from RGB to IHS space. After the histogram matching, the PAN image replaces the component I of the IHS transformation. The inverse transformation is then performed, returning to the RBG space.

For the PCA fusion was adopted Troya's approach (Troya, 1999). After the mean and variance equalization, each pair of images generated two new PC1 and PC2 components. This procedure is repeated for the others pairs of bands. At the end, all first components were used to generate the color composite.

In order to perform the WT fusion, the images were decomposed to the levels desired, in this case to the fourth level. As shown in **Figure 4**, this process generates, for each level, 4 new components that contain the color information (low pass band) and the detailed information (D – diagonal, V - vertical and H – horizontal bands). In the level desired, the color component (C) from PAN image decomposition is replaced by the color component from the TM image decomposition. Afterwards, the inverse WT is applied and a synthetic image is generated. This image contains spatial detailed information derived from HRV PAN image as well as color characteristics of the TM multi-spectral images (Ventura et al., 2002). This procedure was performed for each pair of bands.

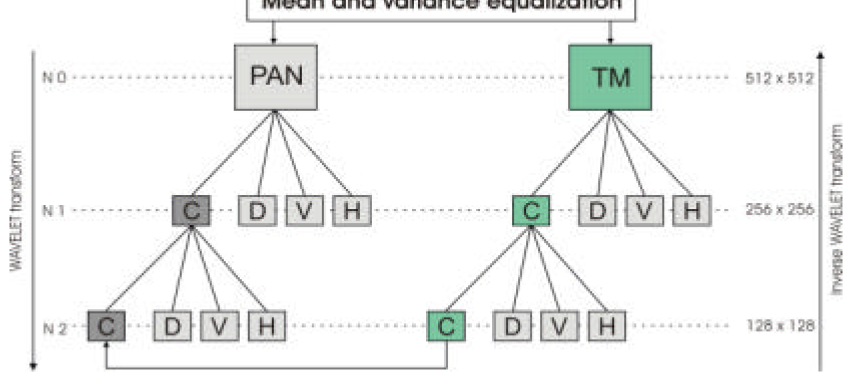

Figure 4 – Schematic methodological sequence of the WT fusion.

C. Fusion Method Evaluation

The evaluation process consisted of visual interpretation, statistical analysis and automatic classification. Initially, a visual interpretation of the resulting synthetic images was performed.

In order to compare spectral quality among original and fused images at the same resolution, synthetic fused images was degraded in a similar resolution to the multi-spectral image (Ventura et al., 2002). In this process was used a nearest neighbor resampler. Thereafter, it was applied low-pass filter projected using the simplified Banon's method (Banon, 1990) in the resample fused image with 30 m resolution. The scene image was selected in areas that do not contained erosion scars and debris deposit areas because these targets influence the full image statistics. The statistical comparison was realized using mean, standard deviation (SD), coefficient of variance (CV) and correlation matrices.

A different method can be used for spatial quality comparison (Li et al., 2002). Laplacian filter was applied in the full image both PAN radiometrically corrected and fused images with 20 m resolution. This process permits the extraction of high pass band that contains the spatial information (high frequency domain). Thereafter, high pass bands was compared using mean, standard deviation (SD) and correlation matrices.

Afterwards, an automatic evaluation was carried out using image classification methods, seeking to minimize the subjectivity of the visual interpretation of the image. To do so, it was necessary to select the adequate classification method for the fusion evaluation. For this evaluation, was used the synthetic image derived from WT fusion because it presented the best results for visual interpretation of the erosion scars.

The MAXVER (pixel-to-pixel) and Bhattacharyya (by region) unsupervised classifiers as well as the non-supervised ISOSEG (by region) classifier were used in this phase. It was defined two classes: *Landslides* (erosion scars on the hillslope and debris deposit areas in the valley floor) and *Others* (other targets such as forests, natural fields, grass, crops, bare soil, etc.). Once the classifiers were defined, the fusion methods could be evaluated.

To demonstrate the benefits of the WT fusion method, they were classified both synthetic and original images using MAXVER (threshold 100%). Then, a comparative analysis between the classified images was performed. This process consisted of an arithmetic difference operation to verify the information matching.

4. Results and Discussion

A . Visual Evaluation

The resulting images obtained from IHS and PC approaches had the erosion scars and debris deposition areas enhanced in relation to the other targets in the scene. These features presented light and pale tones, contrasting with forest, natural fields, etc. However, for both approaches one can verify that it was not possible to obtain a good detail in the landslide areas. For example, grass, natural fields and vegetation cover in the early growing stages were not well discriminated. It was also possible to notice a defocusing in the image, which made the erosion scars look like stains instead of linear features.

On the other hand, the WT synthetic image evidenced the erosion scars, showing them with clear and pale tones as well as with rectilinear and elongated shapes (**Figure 5**). The boundaries of the scar areas became distinct from the boundaries of the other targets. Due to the preservation of spectral characteristics, it was possible to discriminate more precisely other targets existing in the scene. After the spatial resolution enhancement, it was also possible to identify several small features of landslides that were not identified using other fusion approaches

B . Statistical Evaluation

According to **Table 1**, the WT fusion method obtained the best statistical results for the comparison spectral quality. The correlation values were above 91% for the 3 and 5 bands evaluated and the CV values were similar the TM bands. Being so, this method showed better the spectral integrity.

The WT fusion method obtained the spatial correlation values were above 53 % for the bands evaluated. Only in the 5th band this method showed better the spatial integrity. However, the other WT bands evaluated showed similar results to the bands of others fusion methods

Table 1 – Spectral comparison results

Band	Mean	SD	CV	Correlation
TM 3	30,16	5,20	0,17	1,00
WT 3	29,91	4,87	0,16	0,91
IHS 3	30,58	5,47	0,18	0,72
PCA 3	127,63	6,22	0,05	0,87
TM 4	89,54	14,55	0,16	1,00
WT 4	73,53	16,40	0,22	0,82
IHS 4	90,74	7,71	0,08	0,55
PCA 4	120,23	13,82	0,11	0,87
TM 5	90,66	17,47	0,19	1,00
WT 5	90,60	16,44	0,18	0,94
IHS 5	91,48	15,82	0,17	0,74
PCA 5	132,94	17,37	0,13	0,91

C . Evaluation of Classification

The MAXVER classifier (threshold 100%) presented the best results. This can be explained by its' pixel-to-pixel processing operation, which permitted the correct classification of even small scar features, a few pixels wide. It also detailed the occurrence of landslides on the hillslope with more precision in terms of shape and spatial distribution. The region based classifiers, e.g. Bhattacharyya and ISOSEG, took into account neighborhood statistical parameters, which caused the inclusion of small scar features in the class *Others*. They would achieve better results in flat and homogeneous areas of the scene, i.e., plateau and coastal plain.

D . Fusion Methods Evaluation Using MAXVER Classifier

The main difference among the evaluated methods was the occurrence of "false alarms" and the erosion scar feature extraction process. The term "false alarm" means that pixels were incorrectly classified as *Landslides* in areas with low risks of such an occurrence, such as the coastal plain and the plateau. Among all fusion methods, the WT fusion method presented the best results because it permitted to distinguish the erosion scars and debris deposition areas more easiness, confirming the results observed in the visual evaluation.

E . Comparative Analysis Between 453 TM Color Composition and WT Synthetic Image Using The MAXVER Classifier

Figure 6 shows the "image difference" obtained by working out the difference between the classified WT synthetic and the classified original images. The dark blue color corresponds to targets classified as *Others* for both images (89.97 km^2). The cyan color represents erosion scars and debris deposition areas classified as *Landslides* for both images (6,05 km^2). Yellow color represents regions in the scene that were classified as *Landslides* in the original image and as *Others* in the synthetic image (8.06 km^2). The synthetic image resulted in a better classification that original image because the scar features could be better discriminated in relation to the other targets in the synthetic image. Finally, the red color (0,77 km^2) corresponds to areas that were classified such as *Others* in the original image whereas *Landslides* in the synthetic image.

Most of the *yellow* region, mainly in the left side of **Figure 6**, corresponded to "false alarms" in the original image, which means that the synthetic image led to a better result. It is possible to observe that the red region, corresponding to landslide regions, are small and can't be detected by low-resolution TM bands. However, they could be correctly classified in the high-resolution synthetic image obtained in the present study.

5. Conclusions

Any image fusion technique distorts the original multispectral imagery to a certain extent, but the WT fusion method presents the best result for erosion scar identification in both visual and quantitative evaluations. This can be explained by the improvement of the spatial resolution and preservation of the spectral information. Moreover, the WT method maintains the high spectral correlation with respect to the original multispectral images for all bands. Besides it shows the good spatial correlation essentially for the 5th band.

The comparative analysis carried out between the 453 TM and WT synthetic image showed significant improvement for the erosion scars and debris deposition areas identification. Although this approach did show good results for the identification of erosion scars, it is still necessary to evaluate its potential in other areas where such phenomena occurs, and to test images obtained from other sensors.

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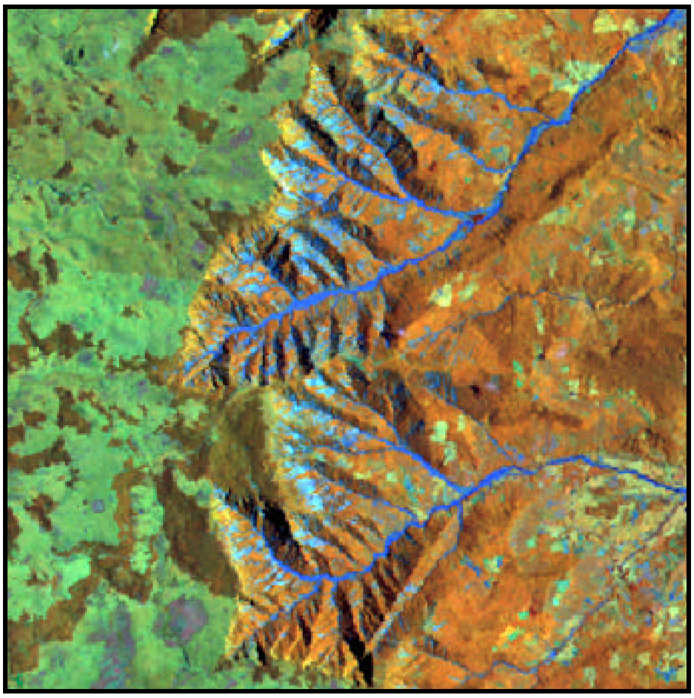

Figure 3 – Color composition TM 453 with 30 m resolution.

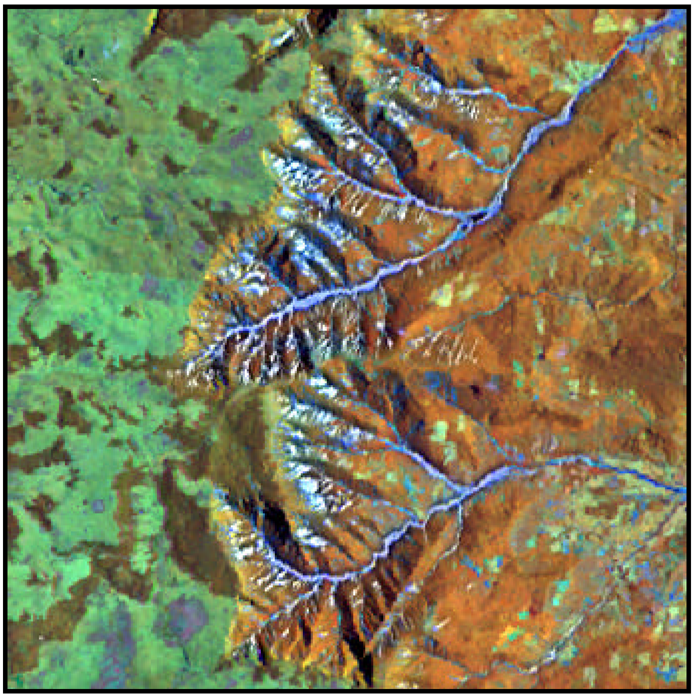

Figure 5 – Wavelet fusion synthetic bands composition with 20 m resolution.

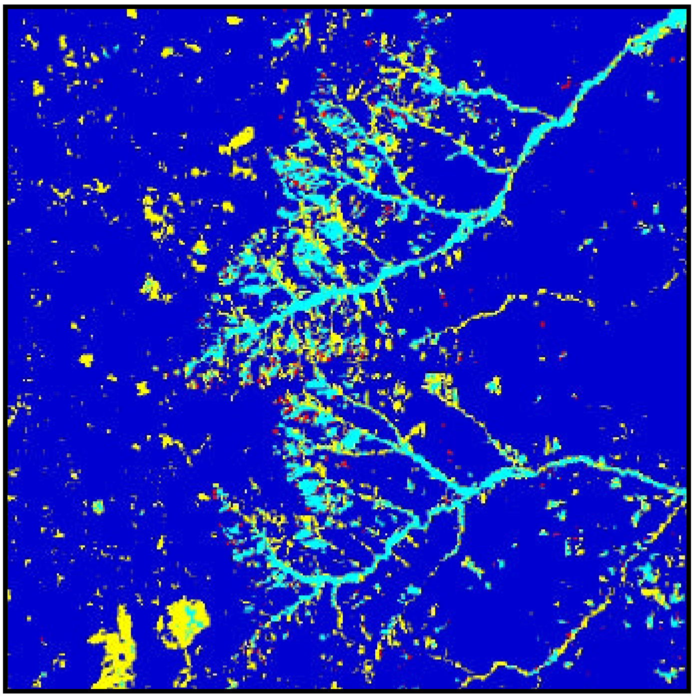

Figure 6 – Difference image between WT and original classified synthetic images.