Satellite Image Enhancement by Controlled Statistical Differentiation

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Abstract - This paper presents a new method of statistical differencing for the enhancement of contrast images. Our approach controls the sharpening effect using two constants in such a way that enhancement occurs in intensity edges areas and very little in uniform areas. It has been proven that our method is superior to similar existent and can be applied to pre-process satellite images.

I. INTRODUCTION

Physical and psychological experiments have shown that photographs or images with edges enhanced are more visual satisfying than an exactly reproduction. But the graphical purposes of image processing are not the only field where such techniques are required. The results of recognition stages in computer vision are improved when suitable pre-processing like edge enhancement is applied [1].

The classic unsharp masking technique [9] is widely used and it is based on a highpass filter. Being simple and effective, the method suffers from several disadvantages: it is highly sensitive to noise and produces undesirable artifacts, particularly in uniform areas.

Some approaches have been proposed in the direction of noise sensitivity reduction. An adaptive filter [4] has been used to emphasize the medium-contrast details in the input image more than large-contrast details such as abrupt edges to avoid artifacts in the output image.

An overview of enhancement techniques can be found in [5] and [9]. In the purpose of non-photorealistic edge enhancement for 3D computer graphics, Nienhaus and Doellner [2] are using the edge map as a locality information. A multiresolution approach is given by Wang, Wu, Castleman and Xiong [3] in the aim of chromosome image enhancement, using differential wavelet transforms. Other multiresolution methods are using a Lapacian pyramid [6].

The rest of the paper is organized as follows, section II presents the actual statistical differencing methods, section III describes the proposed method and section IV specifies an analytical investigation of the enhancement capability of our method. The concluding remarks are made in section V.

II. STATISTICAL DIFFERENTIATION IMAGE ENHANCEMENT

Statistical differentiation has been first proposed by [9] and implies the division of original pixels $F(j,k)$ by their standard deviation $S(j,k)$:

$$G(j,k) = \frac{F(j,k)}{S(j,k)} \quad (1)$$

Where

$$S(j,k) = \frac{1}{W^2} \sum_{m=j-w}^{j+w} \sum_{n=k-w}^{k+w} [F(m,n) - M(j,k)]^2 \quad (2)$$

is the standard deviation computed for every pixel on a WxW window and W=2w+1. $M(j,k)$ represents the estimated mean value for the pixel having coordinates the (j,k) and computed on a same sized window:

$$M(j,k) = \frac{1}{W^2} \sum_{m=j-w}^{j+w} \sum_{n=k-w}^{k+w} F(m,n) \quad (3)$$

The enhanced image $G(j,k)$ has a significant increase in magnitude for pixels that are different from neighbors and a decrease of magnitude for similar pixels. This process has some resemblance with automatic gain control in electronics.

Lee [8] proposed the following method for enhancement:

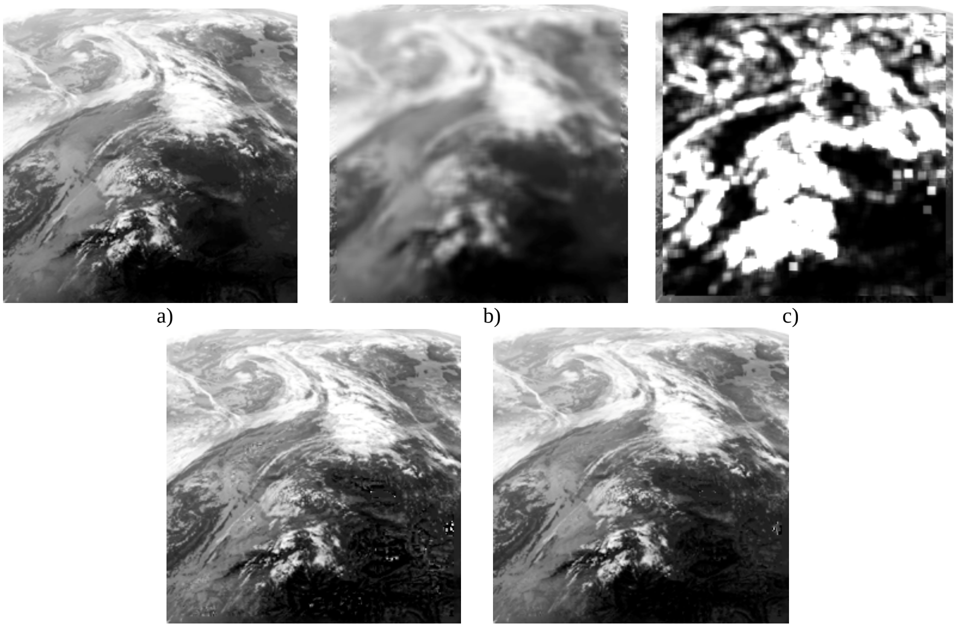
$$G(j,k) = M(j,k) + A(F(j,k) - M(j,k)) \quad (4)$$

with A a constant influencing the degree of enhancement, having current values in the range of [0.2, 0.7]. Wallis [11] has first extended equation (4) to:

$$G(j,k) = M_d + \frac{S_d}{S(j,k)}(F(j,k) - M(j,k)) \quad (5)$$

employing a desired mean value M_d and a desired standard deviation S_d.

The mentioned author also suggested a generalization of the differenting operator, in which, the enhanced image is forced to a specific form, with desired first-order and second-order moments:



a) b) c)

d) e)

Fig.1. Wallis statistical differencing on a satellite image. a) Original image, b) mean image, c) standard deviation, d) enhanced image for r=0.1, A=4, M_d=0.5, S_d=0.33, e) r=0.8, A=4, M_d=0.5, S_d=0.33

$$G(j,k) = [F(j,k) - M(j,k)]\left[\frac{AS_d}{AS(j,k) - S_d}\right] + [rM_d + (1-r)M(j,k)] \tag{6}$$

where M_d and S_d represents the desired mean and standard deviation, A is a gain factor which prevents lager values when $S(j,k)$ is too small and r is a mean proportionality factor controlling the ratio between the edge and the image background.

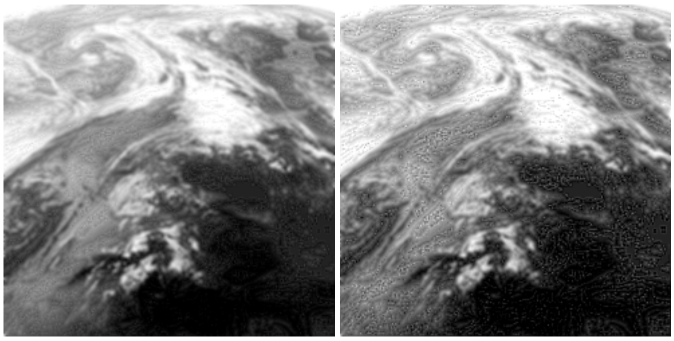
In figure 1 is presented an example of Wallis enhancement method, for two different desired mean and standard deviation factors, using a W=7 window.

III. A NEW METHOD FOR DIFFERENTIAL ENHANCEMENT

Enhancement techniques are principally based on a high-pass filter convolution mask or on the statistical properties of neighborhood pixels as in the Lee (4) and Wallis enhancement method. One can observe that in equation 5, the variance of the pixels is used to enhance the edges by a weighted addition (inverse to variance) of the difference between the original image and the mean image. In this case, for small values of variance (neighbor pixels are alike) the weight will be important and consequently image noise will be enhanced.

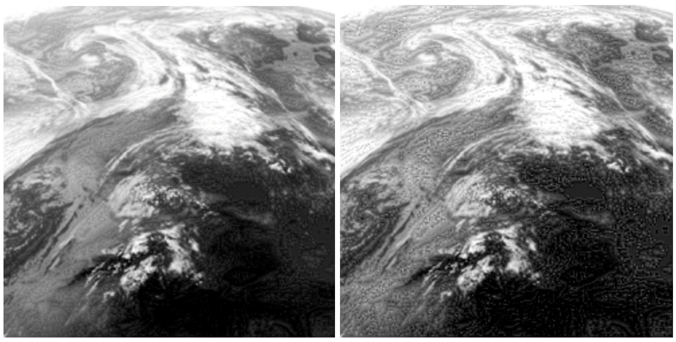
Figure 2 shows the influence of the variance, using two extremes and opposite values on the enhancement of satellite images.

From the equation 5 and also from the resulting images, it can be noticed that, using the mean value, uniform areas are also enhanced. Replacing the mean value by the original value of the pixel in the same equation, the enhancement effect will be improved, but the effect on uniform areas will remain, as shown in figure 3.



a) b)

Fig.2. Satellite image enhancement using the Wallis method for desired variance a) S_d=20 and b) S_d=60.



a) b)

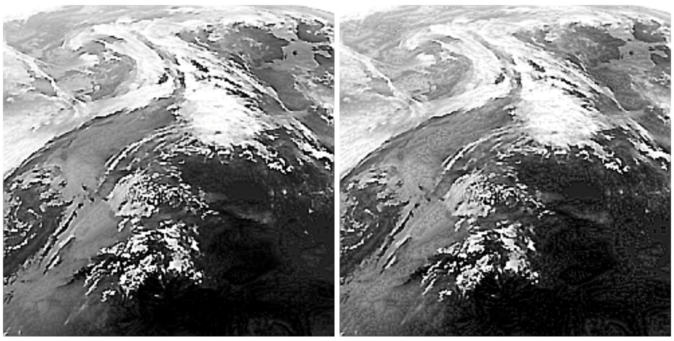
Fig.3. Satellite image enhancement using the modified Wallis method for desired variance a) S_d=20 and b) S_d=60.

Satellite images present a high variance of pixels, due to the nature of the phenomenon implied and to the integration effect of sensor (ground resolution). After testing several adaptive methods in view of cloud motion detection, none of them were satisfactory. Based on our experience [12] in processing this particular type of images, we are proposing a new method adapted to the context.

In order to perform an adaptive and distinct enhancement of homogenous and gray level discontinuity areas, we have developed empirically, the following filtering method:

$$G(j,k) = F(j,k) + \left(F(j,k) - M(j,k)\right)\frac{S(j,k)}{A} + \left(F(j,k) - M(j,k)\right)\frac{B}{S(j,k)} \quad (7)$$

where A and B are constants influencing the enhancement of edges and uniform areas, respectively. In the case of satellite images, optimal values determined for A are in the range [50, 150], and for constant B in [10, 40]. The windows size for variance estimation $S(j,k)$ and mean value of pixels is WxW, having $W=2w+1$ and $w \in \{1,2,3,4\}$. Figure 4 shows the results of the enhancement process, using different values of the two constants and $w=1$.



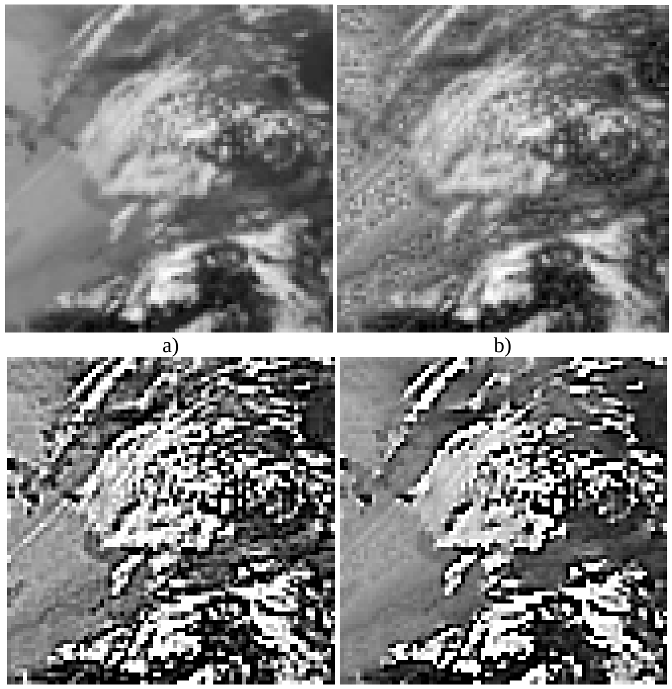
a) b)

Fig.4. Results of the proposed enhancement method using different values of the constants a) A=50, B=20 and b) A=100, B=50.

In the purpose of visual comparison, we are presenting in figure 5, a zoomed subimage of the original one shown in figure 1 a) and enhanced subimages using different methods. One can observe the differential enhancement effect produced by our method together with the improvement in processing uniform areas.

IV. EXPERIMENTAL INVESTIGATION

In the aim of an analytical investigation of the enhancement capability of our proposed method in comparison with other techniques using the statistical differentiation, we have carried out several tests. First, we have established the conditions for a proper comparison using the constants in equations 4, 5 and 7, setting the enhanced image variance to a value of 80. In the case of the Lee method the constant A has a value of 4, the Wallis constant S_d was determined as 80, and for our method, A=200 and B=40. The window size was w=1 (3x3 pixels). The relative high value of variance is creating a high order enhancement effect, supporting the scope of the analysis.



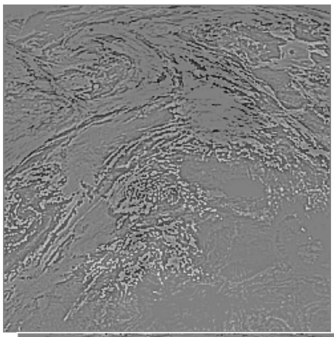
a) b) c) d)

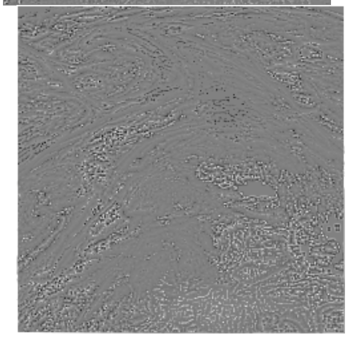
Fig.5. Comparison between different enhancement methods; a) 2x zoom of the image in fig. 1a) within coordinates (60,110) and (140,190); b) Wallis enhancement method; c) enhancement using a classic convolution mask [7]; d) our method.

First of all, we have tested the capability of differential enhancement effect on uniform areas, by subtracting the original image form the enhanced one and forming the error image. The gray-scale value of 128 represents a null variance, while negative and positive values are corresponding to black respectively white side. From figure 6, it can be observed a smaller dispersion of errors in the case of our method compared with the other investigated.

In the case of the Wallis statistical differencing, one can observe the high gain in uniform areas, also visible as a high error rate. As expected, the classical unsharp masks have a global effect, while in the case of our method, error histogram shows that a large number of pixels remain unchanged. Also, the enhanced pixels present a small difference, smaller than other methods. As an issue, the resulting image has no artifacts and the edges have no distortion.

In table 1, a comparative analysis of the 4 methods is represented, using approximately the same variance value of the enhanced image. The error and the number of unaltered pixels are showing that our method performs better. The initial value of the variance for the test image was 74.02, and the gray level mean value 124.76.





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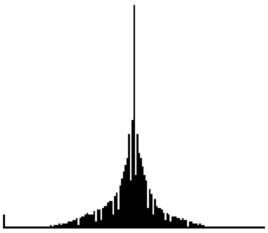

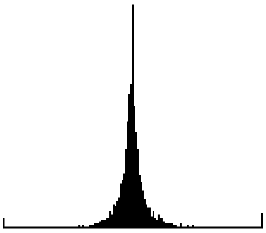

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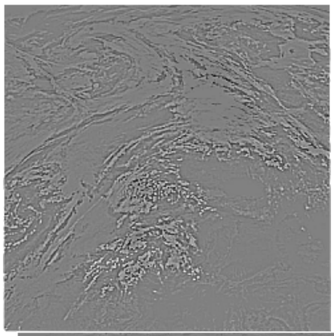
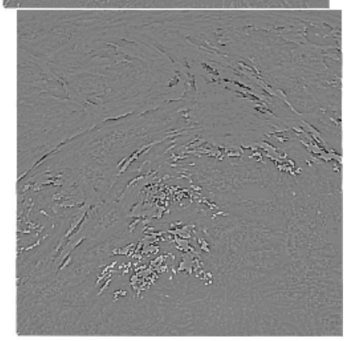
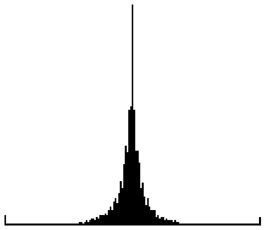
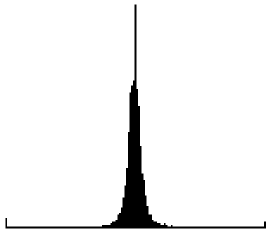




e) f)





g) h)

Fig.6. Error image and histogram for different enhancement methods; a) classical unsharp mask [9] and c) corresponding histogram; b) Wallis method and d) histogram; e) Lee and histogram g); f) our method and the corresponding h) histogram.

In order to prove the satisfactory results obtained (visually and analytically), we have also tested the enhancement effect on gaussian smoothed images. The motivation of such a test consists on the potential edge recovery and enhancement after a smoothing degradation. Three statistical differencing methods were tested, Lee, Wallis and the proposed one, using the same initial conditions and returning approximately the same enhancement variance. The smoothing was performed by a 5x5 gaussian convolution mask and several dispersion values σ. After the enhancement process, based on the computed error, a histogram was created and the error dispersion represented as shown in table 2. It can be seen that our method is superior to Wallis and close to Lee, in enhancing the smoothed edges.

The RMS error was determined for different values of σ ranging in [0.6, 2] with a step of 0.1. RMSE is decreasing while smoothing increase and our method performed equal to Lee. If constants A and B where restored to the previous optimal determined values, our method displayed smaller errors. Figure 7 presents the evolution of RMS with gauss parameter σ.

V. Conclusion

Based on several tests and results, the proposed method for statistical differencing enhancement was superior to all techniques encountered and investigated. If the differential enhancement capability is take into account, our method could be the only one adapting locally to uniform and non-uniform areas based on its intrinsic adapting capacity.

We also believe that having the possibility to adjust the degree of enhancement for edges and uniform areas offers a high efficiency, also shown for satellite images [12].

Table 1: Comparison between enhancement methods

Method	Variance of enhanced image	Gray level mean value	Variance of difference image	Unaltered pixels

Unsharp mask	89.87	121.30	28.36	4230
Wallis	78.28	124.87	21.76	2682
Lee	80.01	124.44	23.11	4983
Our method	79.61	124.41	20.12	5056

TABLE 2: ERROR DISPERSION FOR DIFFERENT GAUSSIAN SMOOTHING

Method / Gauss	σ=0.75	σ=1	σ=1.4	σ=1.6	σ=2
Lee	10.83	4.60	7.06	8.41	10.04
Wallis	12.30	12.27	13.15	13.68	14.68
Our method	10.54	7.16	9.44	10.37	11.59

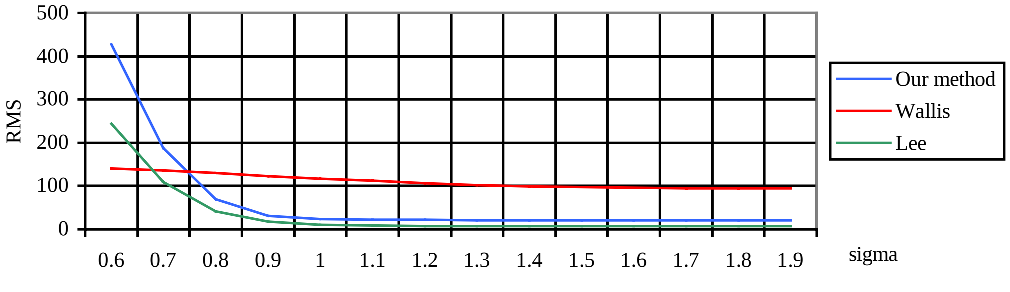


Fig.7. Evolution of RMS for different enhancement methods

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