Adaptive Dynamic Range Reduction for SAR Images.

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Abstract

The visualization of SAR images involves the mapping of high dynamic range amplitude values to gray levels for lower dynamic range display devices. This dynamic range reduction process determines the visibility of details in the displayed result. It is therefore an important part of SAR visualization systems.

The problem of dynamic range reduction for SAR images is related to the tone mapping problem for optical images. Tone mapping is used to prepare high dynamic range optical images for display on lower dynamic range display devices.

In this paper, we present new dynamic range reduction methods for SAR images. The methods are based tone mapping techniques. They are adaptive, improve the visibility of local details, and are suitable for use in interactive visualization systems.

1 Introduction

Visualization of single look complex SAR images usually involves mapping of amplitude values to gray levels. The dynamic range of such amplitude values is typically much higher than the dynamic range of conventional display devices. Therefore, this visualization process implies dynamic range reduction.

Usually a global transformation function is used to map the amplitude values to $[0, 1]$. The result is then linearly mapped to gray levels, i.e. to 8 bit values. Commonly used transformation functions are variants of logarithmic mapping or gamma mapping [1].

The problem of dynamic range reduction for SAR images is related to the tone mapping problem for optical images. Tone mapping is used to prepare high dynamic range optical images for display on lower dynamic range display devices. For this purpose, tone mapping operators (TMOs) reduce the dynamic range of the luminance of optical images. Tone mapping techniques can be applied to SAR images, although there are significant differences, e.g. different noise properties [1].

Global TMOs use an identical mapping function for all image pixels. In contrast, local TMOs map pixels depending on their neighborhood. Bright pixels in dark areas are treated differently than bright pixels in bright areas. This gives local TMOs more flexibility both for reduction of the dynamic ranges and for preservation of local image details. A number of global and local TMOs have been proposed in recent years; see [2] for an overview.

Common to most local TMOs is that they compute a local adaptation value from a neighborhood and use this value to determine how to treat the current pixel. Such local adaptation values are variants of local averages.

A distinguishing feature of a local TMO is the method it uses to compute these adaptation values. The first local TMOs used simple Gauss filters, but that led to large halo artefacts (contrast reversals) at the boundary of bright image features [2].

More recent TMOs use various strategies to avoid computing averages across borders between image regions of different brightness. This reduces undesired halos. However, small halos in largely homogeneous regions are desired because they emphasize details that might otherwise be lost [2].

Methods to compute local adaptation values include bilateral filtering [3] and Gauss filtering with a locally varying filter size [4, 5].

Ideas and methods from tone mapping can be adapted and applied to dynamic range reduction of SAR images. Adapting global TMOs can lead to valuable alternatives to commonly used dynamic range reduction methods. The Schlick [6] and Reinhard/Devlin [7] methods were found to produce good results while being easily adjustable using intuitive parameters [1].

The main problem of adapting local methods is to find a suitable method to compute local adaptation values for SAR images. Because of the different properties of SAR images and optical images, methods developed for optical images give unsatisfactory results [1].

In this paper, we present new adaptive methods for dynamic range reduction of SAR amplitude images. The methods are based on tone mapping techniques, but are tailored to the properties of SAR images. They use intuitive parameters and are implementable on graphics processing units (GPUs), which makes them suitable for interactive visualization and exploration of large SAR data sets [8].

2 Dynamic Range Reduction for SAR Images

Dynamic range reduction methods for SAR images compute display luminance values $L \in [0,1]$ from normalized amplitude values $A \in [0,1]$ using a mapping function f. Normalized amplitude values are available once the maximum amplitude of the original image is known.
For global methods, the function f depends only on the amplitude value of the current image pixel:

$$L(x,y) = f(A(x,y))$$

For local methods, f depends on a neighborhood $\mathcal{N}(x,y)$ of the current pixel instead:

$$L(x,y) = f\left(\{A(x',y') | (x',y') \in \mathcal{N}(x,y)\}\right)$$

The mapping function of global methods is usually monotonically increasing. Brighter pixels in the displayed result are known to be caused by larger amplitude values.
This is not necessarily true for local methods, because local methods can treat the same amplitude value differently depending on its neighborhood. The comparability of resulting gray levels is lost, but local contrast can be enhanced to improve the visibility of details.
Interactive visualization systems allow to use global and local methods simultaneously, thus combining the benefits of both [1] (see Fig. 1).
In the remainder of this section, we will first describe the global dynamic range reduction methods derived from the Schlick and Reinhard/Devlin TMOs, and then describe how to extend these methods with local adaptation values to obtain local adaptive dynamic range reduction methods for SAR images.

2.1 Global Methods

The Schlick Uniform Rational Quantization method [6] uses the following global mapping function when applied to SAR images [1]:

$$L(x,y) = \frac{bA(x,y)}{(b-1)A(x,y)+1}, \quad b \in [1,\infty) \qquad (1)$$

The single parameter b determines the brightness of the result, which makes this method easily adjustable.
The Reinhard/Devlin Model [7], inspired by photoreceptor physiology, leads to the following mapping function when applied to SAR images [1]:

$$L(x,y) = \frac{A(x,y)}{A(x,y)+(\exp(-b)B(x,y))^m}, \quad b \in [-8,8] \quad (2)$$

$$B(x,y) = (1-c)A(x,y) + cA_{\mathrm{avg}}, \quad c \in [0,1] \qquad (3)$$

$$m = 0.3 + 0.7\left(\frac{1-A_{\mathrm{avg}}}{1-A_{\min}}\right)^{1.4}$$

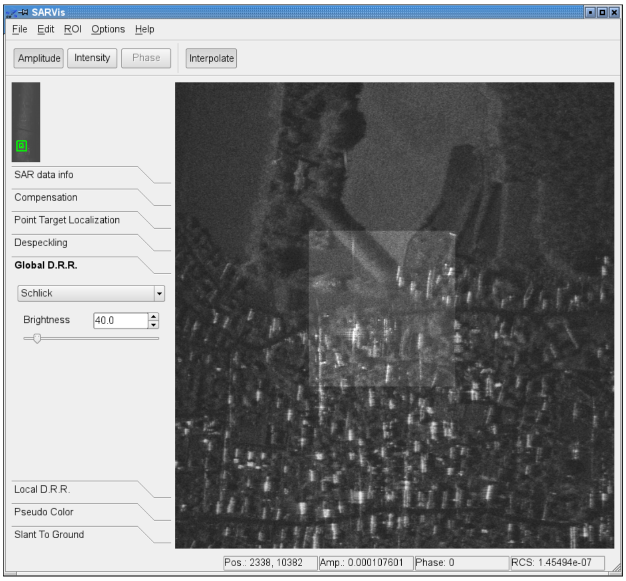

Figure 1: Simultaneous use of global and local dynamic range reduction methods in our interactive GPU-based visualization framework. Data courtesy of FGAN/FHR, processed at ZESS/IPP.

Here, A_{avg} and $A_{\min}$ are the average and minimum normalized amplitude values in the image.
The parameters b and c directly control the brightness and contrast of the result. This allows comfortable adjustment of the resulting gray level images.

2.2 Extension to Local Methods

Both Schlick and Reinhard/Devlin describe extensions to their global methods to make them adaptive to local neighborhoods. Since these extensions do not significantly improve the tone mapping results for optical images, both methods are mostly used in their global variant [2]. However, we found that the extended methods deliver good results for SAR images when used with a suitable method to compute local adaptation values.
The Schlick method is extended by replacing the current amplitude value $A(x,y)$ in the denominator of Eq. 1 with a replacement value $A'(x,y)$. Similarly, the Reinhard/Devlin method is extended by replacing the term $A(x,y)$ in Eq. 3 with $A'(x,y)$.
The replacement value $A'(x,y)$ is computed using a linear interpolation between the current amplitude value $A(x,y)$ and the local adaptation value $A_a(x,y)$:

$$A'(x,y) = (1-d)A(x,y) + dA_a(x,y), \quad d \in [0,1]$$

This allows to steer the amount of adaptivity of each method using the parameter d. For $d = 0$, the extended method is equivalent to the global method, and for $d = 1$ the adaptivity is set to its maximum.
The remaining problem is to find a suitable method to compute the local adaptation values $A_a(x,y)$ for SAR images.

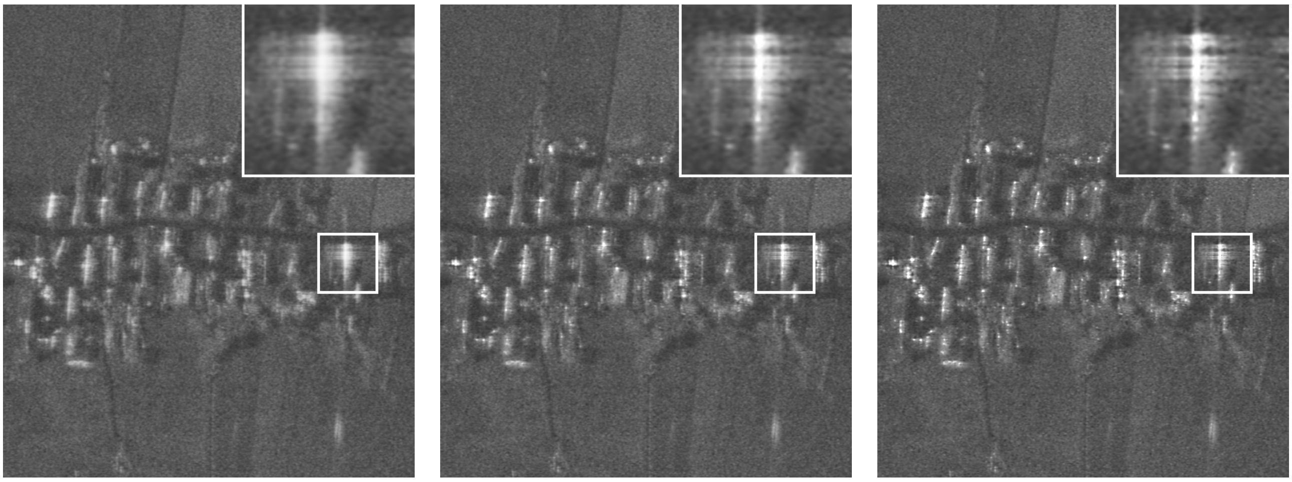

Figure 2: Detail of a SAR amplitude image, visualized using the extended Schlick method with parameter $d = 0.0, 0.5, 1.0$. Data courtesy of FGAN/FHR, processed at ZESS/IPP.

The choice of a method depends on the image features one wants to emphasize. In regions where no features should be emphasized, the adaptivity value $A_a(x,y)$ should not differ much from the current amplitude value $A(x,y)$, so that the method behaves similar to its global counterpart. Around image features that should be emphasized, $A_a(x,y)$ should be the average of a local region, and therefore usually different from $A(x,y)$. The method can then adapt to the properties of local neighborhoods, thereby emphasizing the feature of interest.

In SAR images, major features of interest are peaks in the data that have a considerably greater amplitude than the surrounding region. We propose the following method to compute a local adaptation value $A_a(x,y)$ that accounts for this:

- Compute local averages G_r around the current pixel (x,y) using Gauss filters of increasing radius r, from 1 pixel to 10 pixels.
- Compute quotients $v_{r+1} = \frac{|G_r - G_{r+1}|}{G_r}, \quad 1 \leq r \leq 9$.
- Choose the largest G_r such that $v_r > t$ for a user specified threshold t. If no v_r is greater than t, use $G_1(x,y) = A(x,y)$.

In largely homogeneous regions, this method will choose $A_a(x,y) = G_r(x,y)$ for small values of r or even $r = 1$, which means that the dynamic range reduction will behave like its global counterpart. Around peaks however, the local adaptation value will be the Gauss weighted average of a larger region. This results in an emphasized peak in the gray level image.

Note that this approach is in contrast to the approach used by the Ashikhmin Spatially Variant TMO [4]. In Ashikhmin's method, the largest G_r such that $v_r < t$ is chosen. This results in using large radii in homogeneous regions and smaller ones when boundaries between bright and dark image regions would be crossed otherwise. Image details in largely homogeneous regions are emphasized, and halos around borders between image regions of different brightness are avoided. These properties are suitable for optical images, but not for SAR images.

3 Results

We implemented both the global and local variants of the Schlick and Reinhard/Devlin methods in our GPU-based interactive visualization framework for SAR images [8]. Fig. 1 shows the simultaneous use of global and local dynamic range reduction methods in the framework.

Fig. 2 shows results of the Schlick method. The brightness parameter b was set to 75 in this example. The parameter d was set to 0.0, 0.5, and 1.0 respectively. For $d = 0.0$, the extended method is equivalent to the global method.

Fig. 3 shows results for the Reinhard/Devlin method. Similarly to Fig. 2, the parameter d was set to 0.0, 0.5, and 1.0 respectively. The brightness parameter b was set to -1.5 and the contrast parameter c to 0.9. Setting the contrast parameter to 1.0 would eliminate the influence of the local adaptivity value (see Eq. 3). Therefore, c should not be higher than 0.95.

Setting the threshold t for the computation of the local adaptation values too low will result in emphasized details in all image regions, including emphasized speckle; this is not desirable. Setting the threshold too high will disable all emphasizing effects because the local adaptation value will always be the same as the current amplitude value. In our experiments, we used threshold values between 0.05 and 0.1 for different SAR images from different sensors. The images in Fig. 2 and Fig. 3 were produced using a threshold of $t = 0.05$.

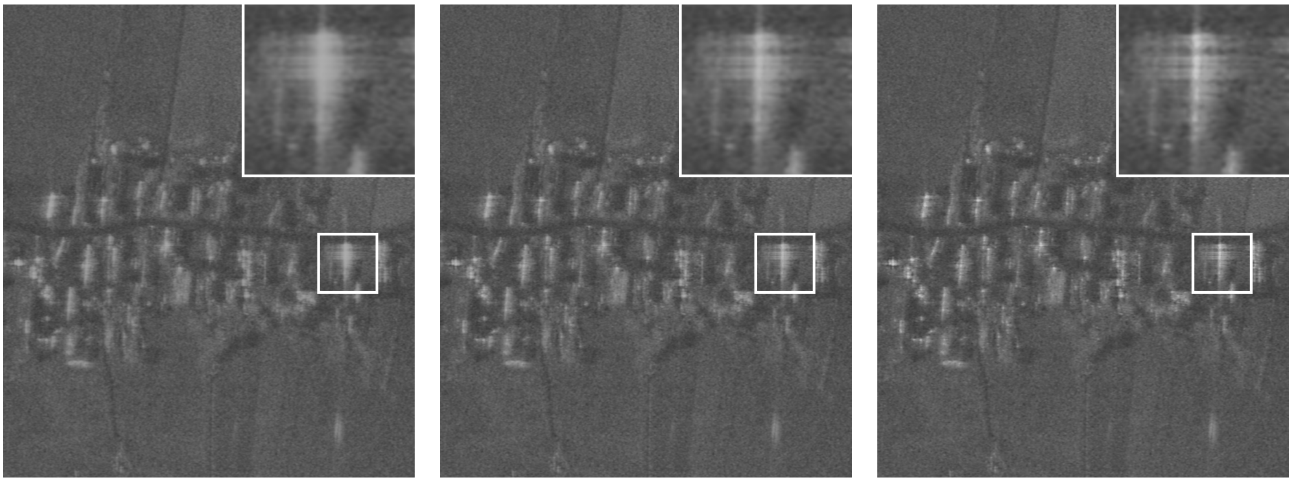

Figure 3: Detail of a SAR amplitude image, visualized using the extended Reinhard/Devlin method with parameter $d = 0.0, 0.5, 1.0$. Data courtesy of FGAN/FHR, processed at ZESS/IPP.

The method to compute local adaptation values for SAR images proposed in Sec. 2.2 can also be used with other TMOs such as the Durand Bilateral Filter TMO [3] or the Ashikhmin Spatially Variant TMO [4]. We chose the Schlick and Reinhard/Devlin methods because of their intuitive parameters and the quality of their results in our tests.

4 Conclusion

We presented new adaptive methods for dynamic range reduction of SAR amplitude images. The methods are based on tone mapping techniques. They are adapted to the properties of SAR images by using a new technique to compute local adaptation values. Visibility of details, especially strong reflectors, is improved in the displayed result.
The methods use intuitive parameters and can be implemented on graphics processing units (GPUs), which makes them suitable for interactive visualization systems.

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